PB81-141939

Chlorine Minimization/Optimization for Condenser Biofouling Control: Final Report

Tennessee Valley Authority
Chattanooga

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Aug 80

U.S. Department of Commerce
National Technical Information Service
NTIS

PB81-141935

TVA

Tennessee
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Energy Demonstrations and
Technology
Chattanooga, TN 37401

EPA

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-80-143
August 1980

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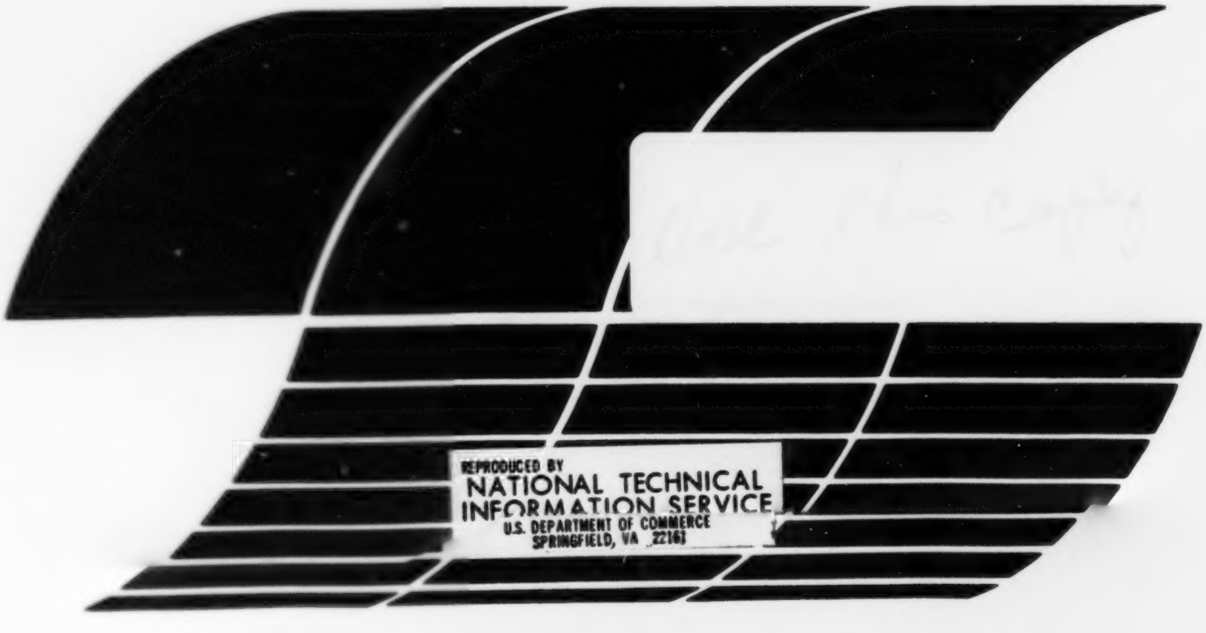
Interagency Energy/Environment R&D Program Report



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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-80-143	2.	3. RECIPIENT'S ACCESSION NO. PB81 141939
4. TITLE AND SUBTITLE Chlorine Minimization/Optimization for Condenser Biofouling Control: Final Report		5. REPORT DATE August 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R. D. Moss, H. B. Flora, II, R. A. Hiltunen, and C. V. Seaman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS TVA, Energy Demonstrations and Technology 1140 Chestnut Street, Tower II Chattanooga, Tennessee 37401		10. PROGRAM ELEMENT NO. INE624A 11. CONTRACT/GRANT NO. Interagency Agreement EPA-IAG-D5-E721
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 12/75-3/80 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is J.W. Jones, MD-61, 919/541-2489. EPA-600/7-79-198 covers study phases I and II.

16. ABSTRACT The report summarizes results of a chlorine minimization/optimization study for the control of biofouling on the surface of condenser tubes at TVA's John Sevier Plant from December 1975 to December 1978. The study concluded that: (1) chlorine feed is a function of inlet water temperature, chlorine demand, and certain water quality parameters; (2) chlorine consumption through the system and consumption of free chlorine across the condenser are directly related to chlorine feed rate; (3) chlorine feed rate at John Sevier could be lowered with no loss of condenser performance if a free residual concentration of 0.1-0.2 mg/l is maintained at the condenser outlet; (4) chlorination must be applied year around, regardless of inlet water temperature; (5) more frequent chlorination cycles of shorter duration are more efficient in controlling condenser performance than infrequent cycles of longer duration; (6) although chloroform, bromodichloromethane, and dibromochloromethane were found at the condenser inlet and outlet at John Sevier, their average concentrations were only 2% of the maximum allowed by Federal Water Quality Crieria; (7) chloroform and dibromochloromethane formation rates are directly related to chlorine feed rate; and (8) chlorination is site specific; i.e., each plant must conduct its own minimization studies, if warranted. An included format assists in such studies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Chlorination	Pollution Control	13B	07C
Biodeterioration	Cooling Water	Stationary Sources	06A	
Fouling Prevention	Water Quality	Biofouling	13H, 13J	
Condenser Tubes			07A	
Condensers			13I	
Chlorine			07B	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES

EPA Form 2220-1 (9-73)

i

EPA-600/7-80-143

August 1980

Chlorine Minimization/ Optimization for Condenser Biofouling Control:

Final Report

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Interagency Agreement No. EPA-IAG-D5-E721
Program Element No. INE624A

EPA Project Officer: Julian W. Jones

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
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ABSTRACT

This report summarizes the results obtained from the chlorine minimization/optimization study for the control of biofouling on the surface of condenser tubes at TVA's John Sevier Steam Plant from December 1975 to December 1978. Many facts about chlorination have become apparent through the data obtained. The following synopsis depicts the salient points gleaned from this study.

1. Chlorine feed is a function of inlet water temperature, chlorine demand, and certain water quality parameters.

2. The chlorine consumption through the system and the consumption of free chlorine across the condenser is directly related to the chlorine feed rate.

3. The chlorine feed rate may be lowered at John Sevier with no loss in condenser performance as long as a free residual concentration between 0.1 and 0.2 mg/l is maintained at the condenser outlet.

4. Chlorination must be applied year round, regardless of the inlet water temperature.

5. More frequent chlorination cycles of shorter duration are more efficient in controlling condenser performance than infrequent cycles of longer duration.

6. Chloroform, bromodichloromethane, and dibromochloromethane were found at the inlet and outlet of the condenser at John Sevier. The average concentrations of these compounds were only 2 percent of the maximum concentrations allowed by EPA, Water Quality Criteria.

7. The chloroform and dibromachloromethane rates of formation are directly related to the chlorine feed rate.

8. Chlorination is site-specific. Every plant must conduct its own minimization studies if warranted, and this report has portrayed a format which will assist in conducting such studies.

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ACKNOWLEDGMENT

We would like to express our appreciation to the following TVA organizations for their support during this study.

Office of Power

Division of Energy Demonstrations and Technology

Environmental Control and Assessment Branch - S. H. Magliente, N. D. Moore, and C. H. Vann

Power Supply Planning Branch - R. L. Thomas

Division of Fossil and Hydro Power

Assistant Director of Fossil and Hydro Power (Fossil Operations) - W. H. Thompson

Technical Services Branch - C. Cain, Jr., E. S. Lisle, C. B. Moultrie, V. C. Shattuck, and J. F. Shiau

Environmental Compliance Staff - D. G. Jahnig

Office of Natural Resources

Laboratory Branch - C. W. Holley, D. G. Carpenter, and J. W. Bobo

Water Quality Branch - R. A. Buckingham, Winford Long, and Charles Petty

Division of Property and Services

Word Processing - Betty C. Bracken

A special appreciation is extended to J. T. Thompson, John Sevier Steam Plant Superintendent, his staff, and the Results Section for their continued cooperation and support throughout this study.

DEFINITION OF TERMS

1. Free Residual Chlorine (FRC)--Also known as free available chlorine. When chlorine reacts with water, hypochlorous acid and hydrochloric acid are formed.

$$\underset{}{Cl_2 + H_2O} \rightarrow \underset{\text{hypochlorous acid}}{HOCl} + \underset{\text{hydrochloric acid}}{HCl}$$

The hypochlorous acid further dissociates into hypochlorite ion and hydrogen ion.

$$HOCl \rightleftharpoons OCl^- + H^+$$

FRC is the sum of the HOCl and OCl^- fractions in the chlorinated solutions.

2. Combined Residual Chlorine (CRC)--When HOCl combines with ammonia in the water, mono-, di-, and trichloramine are formed. The sum of these three fractions is called combined residual chlorine.

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O$$

monochloramine

$$HOCl + NH_2Cl \rightarrow NHCl_2 + H_2O$$

dichloramine

$$HOCl + NHCl_2 \rightarrow NCl_3 + H_2O$$

trichloramine

3. Total Residual Chlorine (TRC)--The sum of the FRC and CRC fractions.

4. Chlorine Demand--The difference between the amount of chlorine added to the water and the amount of FRC, CRC, and TRC remaining at the end of a specified contact period.

5. Chlorine Feed Rate--The total amount of chlorine which would be fed in a 24-hour period if the chlorinator operated continuously. Usually reported in lb/24 hrs.

6. mg/l--Milligrams per liter (10^{-3} g/l).

7. µg/l--Micrograms per liter (10^{-6} g/l).

8. ACF--Apparent Cleanliness Factor. Condenser Performance as calculated by the Heat Exchange Institute.

SECTION 1

INTRODUCTION

In December of 1975, TVA obtained EPA energy pass-through funds for the task entitled, "Study of Chlorinated Water Effluent Quality from a Once-Through Cooling System" under the project, "Characterization of Effluents from Coal-Fired Utility Boilers." Such a research effort was needed to develop a methodology for performing chlorine minimization/ optimization programs needed to comply with EPA effluent guidelines and National Pollutant Discharge Elimination System (NPDES) permits.

NPDES permits for TVA fossil-fueled power plants require that free available chlorine shall not exceed an average concentration of 0.2 mg/l and a maximum instantaneous concentration of 0.5 mg/l at the outlet corresponding to an individual unit. No chlorine may be discharged from any unit for more than two hours per day. In addition, no discharge of free available and total residual chlorine is allowed from one unit while another unit at the same station is being chlorinated. The permit further requires a study be conducted to evaluate all practicable methods to reduce total residual chlorine levels. Other utilities around the United States have received permits containing similarly worded discharge limitations.

Objectives of Study

EPA has contended that a lower feed concentration of chlorine, coupled with an increase in the frequency of the treatment, would result in adequate condenser performance and satisfactory levels of chlorine residuals in the cooling water effluent. Therefore, the purposes of this study were as follows: (1) to determine the amounts of free residual chlorine (FRC) and total residual chlorine (TRC) in a once-through condenser cooling system; (2) to identify the main factors that control chlorine used; (3) to evaluate the interrelationship of these factors with chlorine usage; (4) to evaluate the efficiency of different chlorination practices; (5) to determine the levels of chlorine that are necessary to maintain unit efficiency with increasing chlorine efficiency (optimization) and/or minimization of the use of chlorine; (6) to determine the effect of chlorination of the cooling water system on the formation of chlorinated organics; and (7) to develop a methodology so that TVA and other power utilities may also quantify and evaluate their current chlorination practices.

Approach of Study

Originally, this research effort was to take place at TVA's Kingston Steam Plant. Since a significant seasonal change in the raw water source for this plant results in a corresponding variation of raw water pH, affecting chlorination efficiency, the study was changed to the John Sevier Steam Plant on the Holston River. Although there is some variation in this raw water source, the drastic seasonal change in pH does not occur. This study change was made on January 16, 1976.

In addition to the lack of seasonal pH variation, the John Sevier Steam Plant was chosen for this study due to the nature of its cooling water source, (i.e., the Holston River has a relatively high chlorine demand, high nitrogen content, and high biochemical oxygen demand as compared to the cooling water source at other TVA plants). The Environmental Protection Agency conducted a water quality study on the upper Holston River in 1972 (TS-03-71-208-07)[13]. They determined that the South Fork of the Holston River downstream of Fort Patrick Henry Dam, and the Holston River downstream of the confluence of the North and South Fork, were grossly polluted by five major waste dischargers. Although effluent limitations have been established for these sources and much progress in pollution abatement has been achieved, these rivers are still polluted by a wide variety of waste dischargers.

The research effort consisted of three phases. Phase I in the summer of 1976 was designed to characterize the chlorinated cooling water system at the plant. Phase II in the summer of 1977 consisted of a more detailed study for further understanding the characteristics of the system affecting chlorine use. Phase III in 1978 tested the most optimum procedure for operating the cooling system with minimum chlorine usage.

Due to the need for more definitive data on chemical species that might affect the use of chlorine, the experimental design included the analyses of water samples for the following parameters: ammonia, pH, temperature, alkalinity, total organic carbon, conductivity, total suspended solids, and chlorine demand. Phase I sampling of the intake water was conducted approximately twice per month on the days the chlorinated cooling water system was tested for free and total residual chlorine. During Phases II and III of the study, sampling and testing were conducted weekly.

The chlorinated water samples were analyzed for free and total chlorine residuals. Amperometric and diethyl-p-phenylenediamine (DPD) methods of chemical analysis were used although the majority of the data was collected with the amperometric direct titration method. The sampling stations for all four units during Phase I (see Figure 1) were: (1) the unit intake pump discharge tunnel approximately ten feet from the chlorine injection point (A and A^1); (2) the condenser inlet(B); and (3) the condenser outlet(C). Sampling of chlorinated water at locations A, A^1, B, and C (Figure 1) was initially scheduled to occur several times during Phase I and once per week per unit at locations B and C on each unit during Phases II and III of the research effort. In an effort to identify the efficiency of the present chlorination practice and alternate practices, condenser performance tests (see Sections 4 and 9 for a full description of the calculation of condenser performance) were initially performed once per month per condenser during Phase I and increased to once every two weeks per condenser during Phases II and III.

The approach for determining the effects of chlorination on the formation of chlorinated organics is described in detail in Section 8.

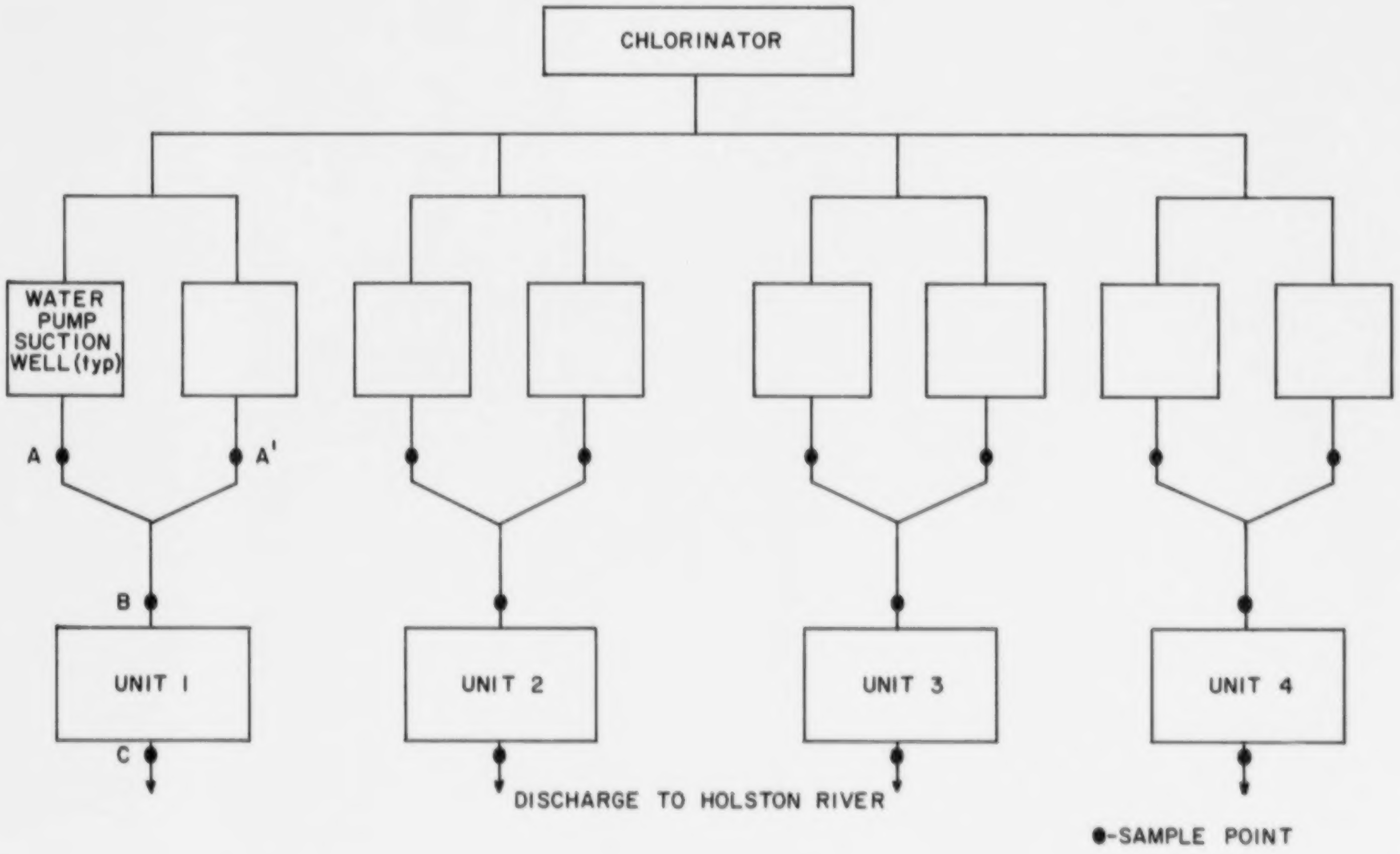
CHLORINATOR
WATER PUMP SUCTION WELL (typ)
A
A'
B
C
UNIT 1
UNIT 2
UNIT 3
UNIT 4
DISCHARGE TO HOLSTON RIVER
●-SAMPLE POINT

Figure 1. Chlorination system at John Sevier Steam Plant.

SECTION 2

CONCLUSIONS

The following conclusions summarize the results obtained from the statistical analyses of data taken from December 1975 to December 1978.

1. The chlorine feed rate required to produce sufficient free residual chlorine at the condenser for maintenance of performance is a function of inlet water temperature and chlorine demand. This would indicate that chlorination regimes are site-specific.

   The following lower limits of feed rate for various intervals of inlet water temperature might be achievable:

Inlet Water Temperature	Feed Rate in Lb/24 hrs
<60°F	1500
60-75°F	2000
≥75°F	2500

   These recommended feed rates are for guidance only; a developmental program in an evolutionary operation should be conducted for each application. This operation should include careful monitoring of condenser performance and chlorine residual levels.

2. Chlorine feed has a direct effect on chlorine consumption through the system and the consumption of free chlorine across the condenser. The chemistry of chlorination is significantly affected by the water quality. The water quality parameters are highly interrelated as to their behavior.

3. The chlorine feed rate may be lowered at John Sevier with no loss in condenser performance as long as a free residual concentration between 0.1 and 0.2 mg/l is maintained at the condenser outlet. The chlorination levels of the temperature dependent scheme followed in Phase III meet the EPA standards at the point of compliance. In addition, based on Phase III data, it appears possible that even lower levels of chlorine feed may be achievable while maintaining adequate condenser performance. However, it appears that the formation of interferences in the residual chlorine measurements caused by such substances as oxidizing agents and certain chloroorganics may increase the chlorine residuals measured above the true values actually present. This means that the estimated lower levels of feed rate given in this report must be approached cautiously.

4. The condensers at the John Sevier Steam Plant cannot be operated without using chlorine to control biofouling, regardless of the inlet water temperatures.

5. Frequency and duration of chlorine feed have an effect on condenser performance as measured by the apparent cleanliness factor (ACF). More frequent chlorination cycles of shorter duration are more efficient than infrequent chlorination cycles of longer duration. The optimum chlorine feed regime for John Sevier is three times per day for 20 minutes or six times per day for 10 minutes for each condenser.

   Other major factors which significantly influenced ACF (after the chlorine dosage) were the inlet water temperature and the amount of free residual chlorine (FRC) at the condenser inlet. The latter, in turn, is significantly affected by water quality parameters such as organic nitrogen and conductivity.

6. The relationship between chlorine demand and the corresponding feed rate at John Sevier may be applied to other TVA power plants to obtain an approximate chlorination regime under different operating conditions by obtaining the following data at the other plants: water quality, (i.e., pH, temperature, ammonia, organic nitrogen, and chlorine demand, etc.), condenser performance history, present chlorination regimes, performance of the chlorinator, and condenser cooling water flow.

   During the chlorine minimization/optimization programs at other plants, the following parameters must be measured: chlorine dosage at the intake, free and total residual chlorine concentrations at the condenser inlet and outlet and at the point of compliance, inlet water temperature, apparent cleanliness factor, turbine backpressure, and water quality data. Monitoring of these data should allow a sequential test program to take place whereby chlorine minimization and optimization (maintaining adequate condenser performance) take place. The particular test program will, of necessity, be tailored to each plant's specific requirements.

7. Chlorinated organics were found at the condenser inlet and outlet in measurable levels. Using the method of industrial, nonoxidant, chromatographable compounds, the largest single measurement was less than 10 μg/l. The following compounds were identified: chloroform, bromodichloromethane, and dibromochloromethane. On the average, these compounds were measured at 5.7 μg/l chloroform, 2.4 μg/l bromodichloromethane, and 0.83 μg/l for dibromochloromethane.

8. Chloroform concentrations and dibromochloromethane concentrations are directly related to the chlorine dosage. Bromodichloromethane formation does not appear to be as strongly influenced by the chlorine dosage.

9. The formation of dibromochloromethane occurs after chloroform and bromodichloromethane formation.

SECTION 3

RECOMMENDATIONS

The following recommendations are made for conducting chlorine minimization/optimization studies:

1. Use a method of measuring chlorine residuals which is relatively quick, accurate, and consistent. The amperometric direct titration method is recommended.
2. Have a good control on the chlorinator feed rate. A recorder is recommended.
3. Monitor turbine backpressure daily.
4. Monitor condenser performance weekly.
5. Do not lower the chlorine feed rate until sufficient time has elapsed to determine the effect of reduced chlorine concentrations on condenser performance (approximately five weeks at John Sevier).
6. Conduct chlorine demand tests on the cooling water as soon as possible after water sample collection. Make measurements at same temperature as collected.
7. While chlorine dosage appears to be the main driving force in the formation of chloroform and dibromochloromethane, the possibility of a secondary reaction between the two compounds appears likely. This factor should be considered in any future studies.
8. Other factors, which could not be identified with the data at hand, also influenced the formation of chlorinated organics. It is suspected that some of these factors are pH, water temperature, water quality, organic precursors, amino acids, and time. These factors will be considered in future studies.

SECTION 4

EXPERIMENTAL LOGIC

Introduction

The overall objective of this chlorine minimization/optimization study was to determine the minimum chlorine feed rates necessary to maintain unit efficiency (assure control of biofouling organisms in the condenser). All reductions in the chlorine feed rate were based upon sound engineering decisions and scientific evaluations of the data.

Chlorine feed rates were systematically reduced during each of the three phases of this study and were based on the results obtained from the preceding phases. At the end of each phase the field test data were statistically analyzed to determine any relationships among the various water quality parameters, the chlorine feed rate, the consumption of chlorine through the system, and the parameters associated with the plant operations. After the data were statistically analyzed, the results of the analyses were studied and evaluated based on chemistry and engineering principles to determine whether the results were possible, probable, or associated with random error. Some of the statistical results were questionable in terms of known scientific principles, but the statistical correlations were so strong in some respects that the results were incorporated into the report to suggest areas for potential research.

The basic factors which were considered in developing the experimental logic included: (1) the method of evaluating condenser cleanliness, (2) the effectiveness of the various chlorine species available for controlling biofouling organisms, (3) chlorine consumption across the condenser, (4) limitations to free and total residual chlorine measurements under field conditions, and (5) variations of chlorine feed rate due to plant equipment and operation.

Method of Measuring Condenser Cleanliness

TVA selected and used the Apparent Cleanliness Factor (ACF) to determine the success or failure of the chlorination regimes investigated during this study. ACF is a method developed by the Heat Exchange Institute[1] (HEI) and the American Society of Mechanical Engineers[2] (ASME) for calculating operating efficiency of the condenser. The ACF is a nondirect method of approximating the occurrence of biofouling, but this method was determined to be the most desirable that was available when the study began. Research is presently underway across the United States to determine better quantitative methods of approximating biofouling growth, the utility industry will continue to use nondirect methods for measuring condenser efficiency such as those described by HEI and ASME.

The ACF is a percentage of how well the consenser tubes in service transfer heat compared to how well a new tube would transfer heat. The basic formula is

$$\text{ACF } (\%) = \frac{U_o}{U_n} \qquad (1)$$

Where: U_o = the apparent heat transfer coefficient of a used tube in $\text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$
U_n = the apparent heat transfer coefficient of a new tube in $\text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$

To calculate U_o and U_n, the HEI and ASME codes require the use of approximately 30 variables. Several of the more important variables are discussed in Appendix J.

Condenser duty, cooling water flow rate, tube velocity, inlet water temperature, turbine back pressure, and the temperature difference across the condenser are variables which greatly affect the ACF. Of these, condenser duty is the most important, and either directly or indirectly affects the other variables. The condenser duty, however, can only be approximated. Therefore, the cooling water flow rate can only be approximated. Since the chlorine feed rate and cooling water flow rate determine the chlorine concentrations in the water, the chlorine regime must be conservative enough to accommodate a change in any of the operation variables, so that neither too much chlorine nor too little chlorine will be injected into the system.

Effectiveness of Various Chlorine Species Available For Controlling Biofouling Organisms

The biocidal ability of a chlorinated cooling water is strongly dependent on the nature of the chlorine residual, and the constituents of the residual are determined by water quality--in some instances almost solely by pH and ammonia nitrogen. At neutral and alkaline pH's, for chlorine to nitrogen molar ratios less than 1:1 (5:1 by weight), the principal component is monochloramine (NH_2Cl) a very poor biocide. Under laboratory conditions hypochlorous acid (HOCl), a potent biocide, is readily distinguished from monochloramine by properly applied standard methods for the determination of free residual chlorine (FRC). Therefore, in many waters FRC is a reliable indicator of biocidal ability.

Both total residual chlorine (TRC) and FRC are toxic to biofouling organisms. Studies have shown, however, that TRC requires a contact period ten times longer than FRC to produce the same toxic effect on *Escherichia coli* organisms.[3,4,5,6] The germicidal efficiency of FRC (primarily HOCL) is due to the relative ease with which it can penetrate the cell wall of a biofouling microorganism. This penetration is comparable to that of water and can be attributed to both its modest size (low molecular weight) and to its electrical neutrality.[3]

The group of organisms which cause condenser biofouling contains some species of organisms more hardy than the relatively sensitive *E. coli*.

Also, a particle of chlorinated cooling water has a condenser residence time of only five seconds, and the total chlorination period is only twenty minutes. This is not long enough for TRC to effectively control biofouling growth. Therefore, FRC, not TRC, was selected as the chlorine species which would best assure biofouling control and maintenance of unit efficiency.

Chlorine Consumption Across the Condenser

"Condenser consumption" can be defined as the loss of FRC as it passes through the condenser. It is important to study the consumption of FRC across the condenser so that adequate amounts of chlorine may be provided at the condenser inlet to ensure that the consumption can be satisfied.

The analysis of the data from Phases I, II, and III indicated the FRC concentration at the condenser inlet was the main factor in determining the magnitude of condenser consumption. Since the FRC concentration is a function of the chlorinator feed rate, the cooling water flow rate, and certain water quality parameters, any variation in factors which control FRC at the condenser inlet will cause variations in the FRC consumed. The analysis of Phases II and III data indicated that alkalinity was a major factor that influenced condenser consumption. The alkalinity, in conjunction with nitrates and nitrites present in the water, and the FRC concentration at the condenser inlet contribute to a phenomenon which was observed on several occasions, during which the FRC concentration was greater at the condenser outlet than at the inlet. Using known theories and principles this phenomena is impossible; however, this must be considered when formulating a recommended chlorine feed rate. (See Appendix K.)

Limitations to Free Residual Chlorine Measurements

The reaction mechanisms associated with FRC measurement procedures and the variabilities of that reaction must be fully understood when making measurements and prescribing feed rates. The lowest FRC level the amperometric titrator can detect is 0.02 mg/l based on the ability of the titrator to measure a particular change of potential across the cell. This limit was determined electronically in the laboratory. In actual use, the minimum detectable level will be higher due to interferences (e.g., copper, iron, etc.) associated with the chlorinated water samples. In addition, the stirring mechanism in the titrator will drastically affect results if the measurements are not conducted swiftly.[7] Also, the needle deflection is ambiguous when nearing the endpoint. Specifically, at lower chlorine concentrations, the beginning of the titration is closer to the endpoint, and it is difficult to determine whether the apparent change in potential is actually a change in potential or electronic drift. A drift problem was found to occur in the field at most chlorine concentrations, but it became worse at theoretically calculated concentrations of 0.15 mg/l and below. This problem is further elucidated in the field measurements of FRC at the condenser, the standard deviations from the steady state average ranged from 0.02 mg/l to 0.30 mg/l. But, it must be noted that these variations were obtained from only one operator performing all tests. The measurements of low-level FRC concentrations is a judgment call on the part of the operator. Therefore, there may be significant differences between operators with respect to evaluating a needle deflection as a change of potential or electronic drift, which could add an additional variable, particularly at very low chlorine concentrations.

After an analysis of the chlorine residuals with respect to breakpoint chlorination, even more doubt is shed on the ability of the methods of measurement to accurately determine low-level chlorine concentrations in the field.[4] Many surface waters contain organic sources of reduced nitrogen that react with chlorine. Even at Cl:N molar ratios less than 1:1, chlorine reacts with these substrates to produce combined forms of chlorine that behave as FRC in the usual colorimetric and amperometric detection methods. If applied chlorine doses are greater than a 1:1 molar ratio, di-substituted N-chloro compounds are formed that are even more likely to behave as FRC.

A significant portion of this organic nitrogen is composed of amino acids and heterocyclic bases such as the purines, pyrroles and pyrimidines.[5,8] Due to their low volatility, polar nature and reactivity, these compounds are difficult to detect by the more widely used Gas Chromatographic (GC) analytic procedures. Improved Liquid Chromatographic (LC) techniques have led to the separation and confirmation of many individual compounds.[9] Nevertheless, the major fraction of organic nitrogen in surface waters usually remains uncharacterized.

In their study of chlorinated amino acids and nitrogen bases, Wajon and Morris[10] concluded that all methods currently employed to measure free chlorine are subject to interferences of varying degrees that depend on the particular compound present. Thus, problems such as changes in water quality characteristics encountered during the John Sevier studies may have some impact on the accurate measurement of FRC concentrations.

A portion of the data collected during this chlorine minimization study may be found in Table 1. The Holston River is characterized by a high chlorine demand, high biochemical oxygen demand, high TOC, and high total nitrogen. The major constituents of total nitrogen were nitrates and nitrites. In general, the organic nitrogen was usually slightly higher than ammonia nitrogen and varied from 0.07 to 1.30 mg N/ℓ. The total reduced nitrogen, NH_3-N + organic - N, varied from 0.20 to 1.40 mg N/ℓ, values equivalent to 1.00 and 7.00 mg Cl_2/ℓ if a 1:1 stoichiometry is assumed. Because of the high organic nitrogen, one would expect anamolous behavior of free chlorine residuals. This has indeed been the case as can be seen from the following analysis.

The apparent initial molar ratios of chlorine to reduced nitrogen listed in Table 1 range from 0.20 to 2.9. The word apparent is used because the actual ratio is a function of the rate of chlorine consumed (demand) from non-nitrogenous sources. If this rate of demand was slow over the 2.2 minute period from the point of chlorine injection to the condenser inlet, then the apparent ratio is equal to the actual ratio. Rapid demand from sources other than reduced nitrogen, on the other hand, would have lowered the actual ratio.

Chlorine speciation is strongly dependent on this ratio and, for a simple chlorine-ammonia system, the composition of chlorine residuals

Table 1

CHLORINE TO REDUCE NITROGEN MOLAR RATIOS

Date	Unit 3 Chlorine Feed (mg/l)	NH_3 (mg/l)	Org N (mg/l)	NO_2 + NO_3 (mg/l)	Chlorine: Reduced N (Molar)	Inlet Unit 3		pH
						FRC (mg/l)	TRC (mg/l)	
Phase I								
6/9/76	3.75	.26	.13	.78	1.9	.70	1.76	7.6
*6/16/76	3.09	.25	.30	.78	1.1	1.06	1.90	7.6
*7/8/76	2.68	.15	.38	.79	1.0	1.09	1.59	7.6
7/16/76	3.13	.14	.20	.55	1.8	.35	.99	7.5
8/13/76	3.63	.16	.24	.58	1.7	.92	1.61	7.3
Phase II								
*5/6/77	2.66	.81	.07	.74	0.6	.48	1.48	7.8
5/12/77	3.28	.07	.15	.70	2.9	1.60	1.60	8.3
5/20/77	2.85	.12	.18	.70	1.8	1.20	1.44	7.7
*5/27/77	2.82	.21	.27	.67	1.1	.38	1.15	7.8
6/3/77	2.79	.12	.24	.62	1.5	.27	1.30	7.9
6/10/77	2.80	.09	.15	.53	2.3	.78	1.45	8.0
6/17/77	2.81	.14	.11	.62	2.2	.311	1.22	8.0
*6/24/77	2.73	.39	.33	.37	0.7	1.00	1.45	7.5
6/30/77	2.82	.11	.18	.54	1.9	.88	1.44	7.6
7/13/77	2.83	.15	.14	.58	1.9	.87	1.30	7.7
7/20/77	2.85	.06	.14	.50	2.8	.62	.83	7.7
*9/2/77	1.65	.12	.16	.62	1.1	.25	.86	7.4
*9/16/77	1.72	.16	.19	.71	0.9	.39	1.03	7.4
*9/23/77	1.77	.10	.20	.63	1.1	.75	1.10	7.4
Phase III								
*10/28/77	1.11	.07	.13	.65	1.1	1.90	.58	7.5
*11/18/77	1.25	.06	.32	.68	0.6	.07	.55	7.4
*12/22/77	1.11	.04	.22	.76	0.8	.31	.49	7.5
*2/3/78	1.22	.21	.29	.92	0.4	.30	.64	7.5
*4/13/78	1.15	.49	.27	.63	0.3	.24	.61	7.5
*4/28/78	1.92	.10	1.3	.57	0.2	.15	.84	7.3
*5/5/78	2.22	.17	.20	.71	1.1	.03	1.16	7.2
*5/16/78	2.27	.19	.19	.71	1.1	.96	1.09	7.2
*5/23/78	2.18	.15	.23	.79	1.1	-	1.00	7.8
6/6/78	2.20	.09	.13	.69	1.9	.66	1.13	7.7
*6/13/78	1.85	.10	.21	.85	1.1	.36	.85	7.2
6/21/78	1.83	.10	.12	.72	1.6	.45	.84	7.6
6/27/78	1.83	.08	.13	.72	1.7	.59	.79	7.6
*7/7/78	1.81	.15	.18	.95	1.0	.16	.89	7.6
*7/18/78	1.50	.15	.29	.73	0.6	.07	.74	8.2
*7/25/78	1.54	.07	.19	.65	1.1	.18	.66	7.8
*8/2/78	1.58	.12	.16	.67	1.1	.42	.80	7.5

TABLE 1
(continued)

Date	Unit 3 Chlorine Feed (mg/l)	NH_3 (mg/l)	Org N (mg/l)	NO_2 + NO_3 (mg/l)	Chlorine: Reduced N (Molar)	Inlet Unit 3 FRC (mg/l)	Inlet Unit 3 TRC (mg/l)	pH
*8/29/78	1.57	.07	.21	.68	1.1	.44	.74	7.4
*9/6/78	1.56	.07	.21	.53	1.1	.23	.55	8.1
9/19/78	1.56	.08	.16	.74	1.2	.41	.78	7.6
*10/3/78	1.92	.11	.27	.32	1.0	.17	.72	7.5
*10/17/78	1.92	.13	.19	.86	1.1	.75	1.08	7.6
*10/31/78	1.92	.21	.19	.77	0.9	.39	.90	7.4
*11/14/78	1.98	.11	.23	1.00	1.1	.20	.78	7.8

*Days when no FRC should be measured at the condenser inlet (Cl:N ratios $\leq$1.1:1).

may be predicted by the Morris-Wei model as has been shown by Saunier and Selleck.[11] In general for ratios $\leq$ 1.1:1 there is no loss of oxidizing chlorine, and monochloramine is the sole constituent of TRC. As the ratios approach 1.6:1 from the low side, there is an increasing tendency toward dichloramine formation, some trichloramine formation and a more rapid loss of oxidant. At higher ratios (>2), more di- and trichloramine are formed, and there is less oxidant loss. At all ratios above 1.1, some free chlorine is expected. Based on these considerations, no free chlorine should have been measured at the Unit 3 condenser inlet on twenty-eight of the forty-three test dates (65%) shown in Table 1. Given the strong possibility of a rapid non-nitrogenous demand, it is even more unlikely. For the other days, some free chlorine would be expected only if the demand rate were slow. However, the reported values are generally much higher than would be predicted from the ammonia breakpoint model. Although the test measurements for low-level FRC concentrations indicate that FRC is present, this may not be the case. Therefore, the chlorine feed rate must compensate for this by being high enough to actually provide the level of FRC needed to effectively control biofouling.

The problems of measuring true FRC concentrations are further substantiated by a project conducted by the Utility Water Act Group (UWAG).[12] Results from that project indicate that the standard deviation between FRC measurements was 0.033, and that based on a single sample, one had to maintain a FRC concentration of 0.085 mg/l to be 99 percent confident that a residual of zero was maintained. Even though we disagreed on the statistical methods employed by UWAG, TVA calculated from the data that the lowest level of FRC which would accurately be measured was 0.076 mg/l rather than 0.085 mg/l, but the point still remains that residuals below 0.1 mg/l may be suspect.

Variations of Chlorine Feed Rate Due to Plant Equipment and Operation

The feed rate of the chlorinator and the cooling water flow rate determine the chlorine concentration in a condenser system. Because of the inability of the chlorinator to feed chlorine accurately, the chlorinator feed rate is one of the largest sources of variation during the chlorination operation. The chlorinator at John Sevier has a capacity of 8000 lb/24 hrs and the manufacturer's data sheets indicate that this particular chlorinator has a possible maximum variation in performance of 400 lb/24 hrs. The lower the feed rate, the larger the relative variation. At a constant cooling water flow rate, a 2000 lb/24 hrs chlorine feed rate could vary from 1600 lb/day to 24 lb/24 hrs. This would translate into a variation in chlorine concentration between 1.33 mg/l and 1.99 mg/l, assuming a 100,000 gpm flow rate. This amount of variation could result in insufficient chlorine levels to control biofouling or a discharge of excess chlorine.

In addition, another potential source of variation in the chlorination system occurs at the injector. The chlorine is fed into a 4-inch line by a vacuum created across an orifice by a flow of water. If the flow of water is reduced via a faulty pump or debris lodged in the pipe, less chlorine will be added to the cooling water.

The condenser cooling water (CCW) flow rate is also a major source of variation in the chlorination operation. The flow rate is highly dependent on pump performance, which is affected by river elevation, pump efficency, power fluctuations, etc. In addition, the flow rate requirements change frequently to correspond to changes in electrical demand (change in power production) and changes in intake water temperature (change in cooling requirements).

Summary

As a result of the inability to precisely control and measure low concentrations of FRC, it was concluded that an FRC concentration of between 0.1 and 0.2 mg/l should be maintained at the condenser outlet in order to assure biofouling control. This minimum range is based on both theoretical and practical chemistry and engineering principles, and provides a modest safety factor. Even at these minimum chlorine concentrations, however, biofouling may be occurring in the condenser without being detected from ACF calculations. Only operations over a period of time using the proposed procedures will provide the answer.

The above conclusion is basic to the approach taken to minimize chlorine at John Sevier Steam Plant. By maintaining a FRC concentration of 0.1-0.2 mg/l at the condenser outlet, ACF has apparently not been impaired. If there were a better way of estimating biofouling than the ACF, the study recommendations could be more definitive. But if it takes five weeks to see any change in ACF or turbine back pressure at a zero chlorine feed rate (see Section 6 for full details), then it will certainly take much longer to determine the effects of a gradual fouling rate.

The calculations of condenser performance must also be kept in perspective. While it is true that the actual performance during these tests could not be accurately calculated since the heat balance results obtained in the 1950's had to be used, the experimental logic is based on a change in the ACF from year to year. The variations in the factors affecting ACF (i.e., air leakage, condenser duty, CCW flow, etc.) can mask the actual daily and weekly results such that a decrease or increase in ACF could have actually occured, yet the calculation may not indicate such a change due to the random variability of the factors involved.

Reducing the feed rate so that FRC concentrations less than 0.1 mg/l are measured at the condenser outlet risks an unscheduled unit outage at considerable cost (estimated at $100,000 per unit per outage), and does not represent the application of sound scientific principles.

An example of the effects of lowering the chlorine residuals at the condenser outlet below 0.1 mg/l FRC is shown in the following examples:

Assumptions:

1500 lb/24 hrs feed rate = 0.1 mg/l FRC at condenser outlet
CCW flow rate is constant (120,000 GPM)
No change in load or ΔT

No change in water quality parameters
No change in chlorine demand
No ambiguous measurements of FRC at the outlet
Condenser duty is constant
Water flow at chlorinator injector is satisfactory

Variable: Chlorinator feed rate varies ±400 lb/24 hrs.

$$@\ 1500\ \text{lb/24 hrs} = \frac{1500\ \text{lb/24 hr}}{120{,}000\ \frac{\text{gal}}{\text{min}}} \times 83.29\ \frac{\frac{\text{gal}}{\text{min}} \cdot \text{mg}}{\text{lb/24 hrs} \cdot \ell} =$$

$$1.04\ \text{mg/l}\ Cl_2$$

$$\text{less chlorine demand} = \frac{0.54\ \text{mg/l}}{0.50\ \text{mg/l TRC}}$$

$$20\%\ \text{of TRC is FRC} = \frac{x.20}{0.10}\ \text{mg/l FRC at condenser outlet}$$

@ 1100 lb/24 hrs = 0.76 mg/l Cl_2

$$\begin{array}{r} 0.76 \\ -0.54 \\ \hline 0.22 \\ x\ .20 \\ \hline 0.04 \end{array}\ \text{mg/l FRC at condenser outlet}$$

@ 1900 lb/24 hrs = 1.32 mg/l Cl_2

$$\begin{array}{r} 1.32 \\ -0.54 \\ \hline 0.78 \\ x\ .20 \\ \hline 0.15 \end{array}\ \text{mg/l FRC at condenser outlet}$$

Variability of the chlorinator alone yields a range of 0.04 to 0.15 mg/l FRC at the condenser outlet assuming all other variables are constant.

Now assume that all factors are constant and only the CCW flow rate varies. Data collected by the TVA Statistics Section indicate that the heat rate may have only changed 3 percent at John Sevier since 1955, which is quite conservative.

Change in heat rate of 3% = 5% change in condenser duty = 5% change in CCW flow.

$$@\ 120{,}000\ \text{GPM} = \frac{1500\ \text{lb/24 hrs}}{120{,}000\ \text{gal/min}} = 0.1\ \text{mg/l FRC at condenser outlet}$$

$$@\ 114{,}000\ \text{GPM} = \frac{1500\ \text{lb/24 hrs}}{114{,}000\ \text{gal/min}} = 0.11\ \text{mg/FRC at condenser outlet}$$

$$@\ 126{,}000\ \text{GPM} = \frac{1500\ \text{lb/24 hrs}}{126{,}000\ \text{gal/min}} = 0.09\ \text{mg/l FRC at condenser outlet}$$

Variability of 3 percent in the heat rate provides a range of 0.09 mg/l to 0.11 mg/l FRC at the condenser outlet. Again, 3 percent is a very conservative change in heat rate.

For these reasons, we believe a FRC concentration of 0.1-0.2 mg/l at the condenser outlet is the minimum level of chlorine which will assure control of biofouling organisms in the condenser.

SECTION 5

THE PLANT

The John Sevier Steam Plant is located on the Holston River near Rogersville, Tennessee. The plant has four coal-fired boilers which produce a total of 800 MWh. The cooling system is a once-through system which has an average flow of 120,000 GPM through each single-pass, surface condenser. Each condenser contains 11,010 tubes made of inhibited admiralty brass with an outside diameter of 7/8 in. and an overall length of 30 ft.

Two intake suction pumps supply water to each condenser. The distance from the intake pumps to the condenser inlet is approximately 685 ft, and the distance from the condenser outlet to the head of the discharge canal is approximately 550 ft.

The chlorination feed equipment is located at the intake structure. Liquid chlorine is pumped from a railroad tank car into a Wallace and Tiernan evaporator where it is changed to a gaseous state. The chlorine gas is monitored through a Capital Controls 8000 lb/24 hrs capacity chlorinator and is then injected into a 4-inch O.D. pipe. This pipe feeds a chlorine header in the subbasement where individual lines feed chlorine into the bottom of each pump suction well. Automatic valves, which are controlled by electric timers, control the flow of chlorinated water to each unit.

The chlorinator also contains a flow meter-transmitter. This flow meter-transmitter sends a signal to a strip-chart recorder. The signal is based upon the feed rate of the chlorinator. Therefore, regardless of the chlorine flow indicated by the float in the chlorinator, the actual flow is indicated via the flow meter-transmitter-recorder system.

A schematic drawing of the condenser cooling water system and chlorination system may be found in Figure 2.

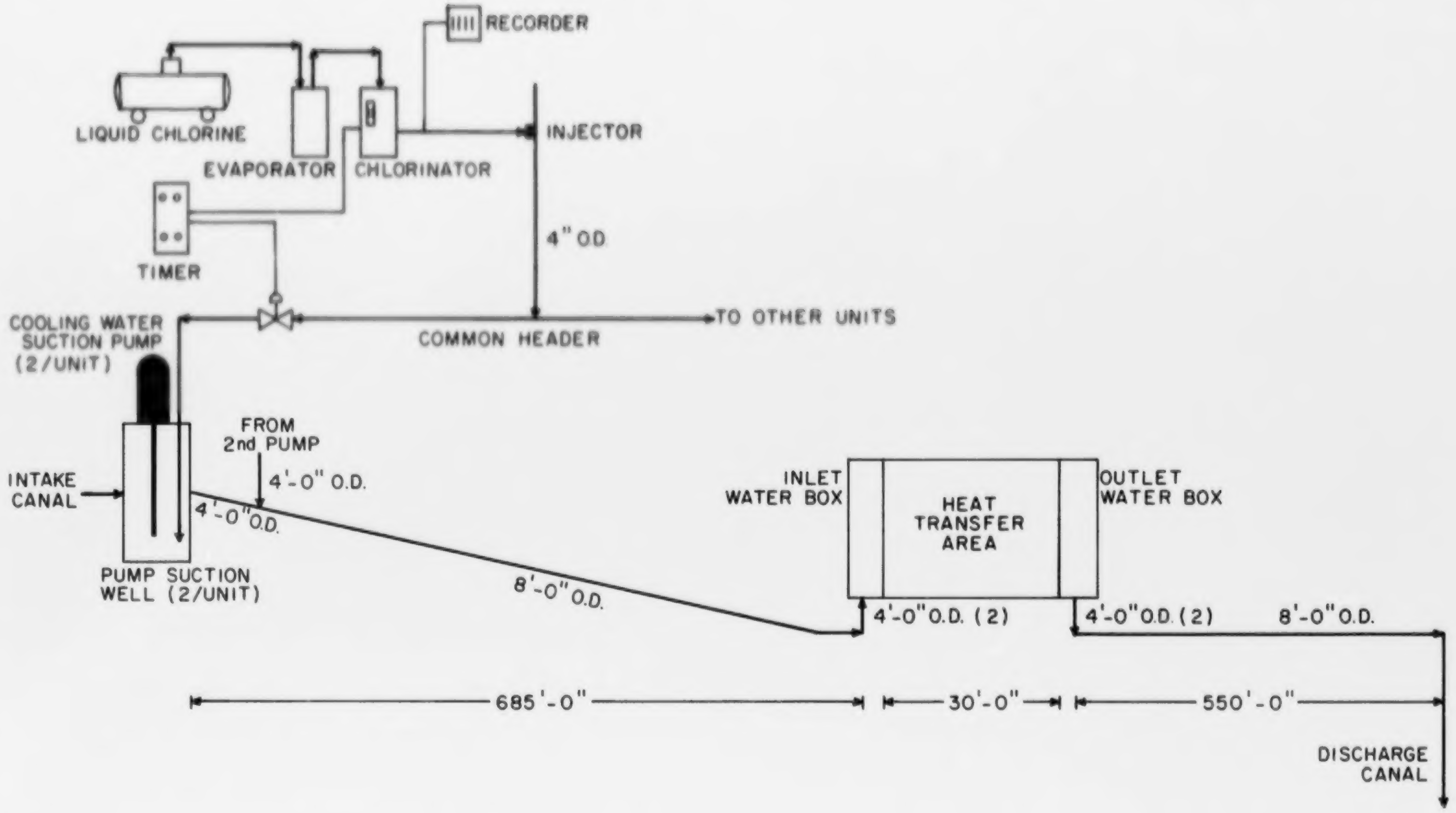
RECORDER
LIQUID CHLORINE
EVAPORATOR
CHLORINATOR
INJECTOR
TIMER
4" OD
COOLING WATER SUCTION PUMP (2/UNIT)
COMMON HEADER
TO OTHER UNITS
FROM 2nd PUMP
4'-0" O.D.
INTAKE CANAL
4'-0" O.D.
PUMP SUCTION WELL (2/UNIT)
8'-0" O.D.
INLET WATER BOX
HEAT TRANSFER AREA
OUTLET WATER BOX
4'-0" O.D. (2)
4'-0" O.D. (2)
8'-0" O.D.
685'-0"
30'-0"
550'-0"
DISCHARGE CANAL

Figure 2. John Sevier condenser cooling water and chlorination system flow diagram

SECTION 6

EXPERIMENTAL PROCEDURE

Preliminary Data

The results of preliminary tests are shown in Table 2. With the condition that the only data considered in the analysis to determine future experiment changes would be data taken during steady state conditions, the following conclusions were obtained from the preliminary testing:

1. Total chlorine measurements taken at the point of chlorination (Points A,A^1 in Figure 1) generally agreed (±10%) with the calculated chlorine based upon the feed rate and flow at the point of chlorination.
2. Total residual chlorine at the inlet to the condenser was approximately 65 percent of the chlorine feed.
3. Total residual chlorine at the outlet of the condenser was approximately 50 percent of the chlorine feed.
4. Chlorine was being consumed within the system.
5. Free residual chlorine measured at the inlet to the condenser varied from test to test with a range of approximately 1 to 2 mg/l. However, the within-test range was approximately 0.3 mg/l.
6. Free residual chlorine at the outlet of the condenser was highly variable from test to test spanning a range of 0.1 to 1.65 mg/l. The within-test variation was small compared to the test-to-test variation.

As part of the data necessary to evaluate the present chlorination practice, the condenser performance data for 1974 and 1975 at John Sevier for Units 1-4 was plotted and found to display a seasonal trend (see Figure 3). The condenser apparent cleanliness factor begins to decline in late March from a value of 80-85 percent (85 percent is the maximum assumed in the HEI calculation[1] for a clean condenser) to approximately 70 percent in late August and then increases to 80-85 percent by November. Typically, the condensers are brush cleaned in the November to March period.

The historical performance (record) of the John Sevier condensers, in conjunction with a control condenser performance record during the chlorination study, would allow a comparison for the effect of different chlorination rates on condenser performance as measured by the apparent cleanliness factor. However, we must note that several other factors also affect the apparent cleanliness factor in addition to biofouling (i.e., inlet water temperature, air leakage, turbine back pressure, etc.).

TABLE 2. JOHN SEVIER MAXIMUM MEASURED CHLORINE RESIDUALS AT CONDENSER INLET, OUTLET, AND INTAKE

Unit	Calculated Chlorine Feed (mg/l)	Free Residual Chlorine (mg/l)	Total Residual Chlorine (mg/l)
INLET			
March 2, 1976 1818-2031			
1	5.26	1.5	3.71
2	5.26	1.74	3.92
3	5.26	1.68	2.46
March 3 0845-1017			
1	5.26	1.52	3.80
2	5.26	2.21	3.68
3	5.26	1.86	3.92
OUTLET			
March 2 0915-0935			
1	5.26	1.56	4.53
2	5.26	0.70	4.00
3	5.26	0.35	2.87
1230-1344			
1	4.38	0.91	2.98
1	3.51	1.20	3.45
1818-2031			
1	5.26	0.99	2.67
2	5.26	1.20	3.40
3	5.26	0.6	1.42
March 3 0845-1017			
1	5.26	1.65	2.69
2	5.26	0.41	2.10
3	5.26	0.33	2.19

Continued

TABLE 2 (continued)

March 11, 1976

Unit	Calculated Chlorine Feed (mg/l)	Free Residual Chlorine (mg/l)	Total Residual Chlorine (mg/l)
		INLET	
1	5.26	1.82	3.76
1	4.38	1.58	3.32
1	3.50	1.02	2.72
2	5.26	1.34	3.51
2	4.38	0.92	2.70
3	5.26	1.4	3.61
3	4.38	0.94	2.91
		OUTLET	
1	5.26	0.42	2.61
1	4.38	0.27	1.10
1	3.50	0.09	0.87
2	5.26	0.21	1.07
2	4.38	0.17	1.05
3	5.26	0.30	1.30
3	4.38	0.10	1.12
		INTAKE	
1	4.38	2.50	4.06
2	4.38	2.19	4.47
3	4.38	2.05	4.57

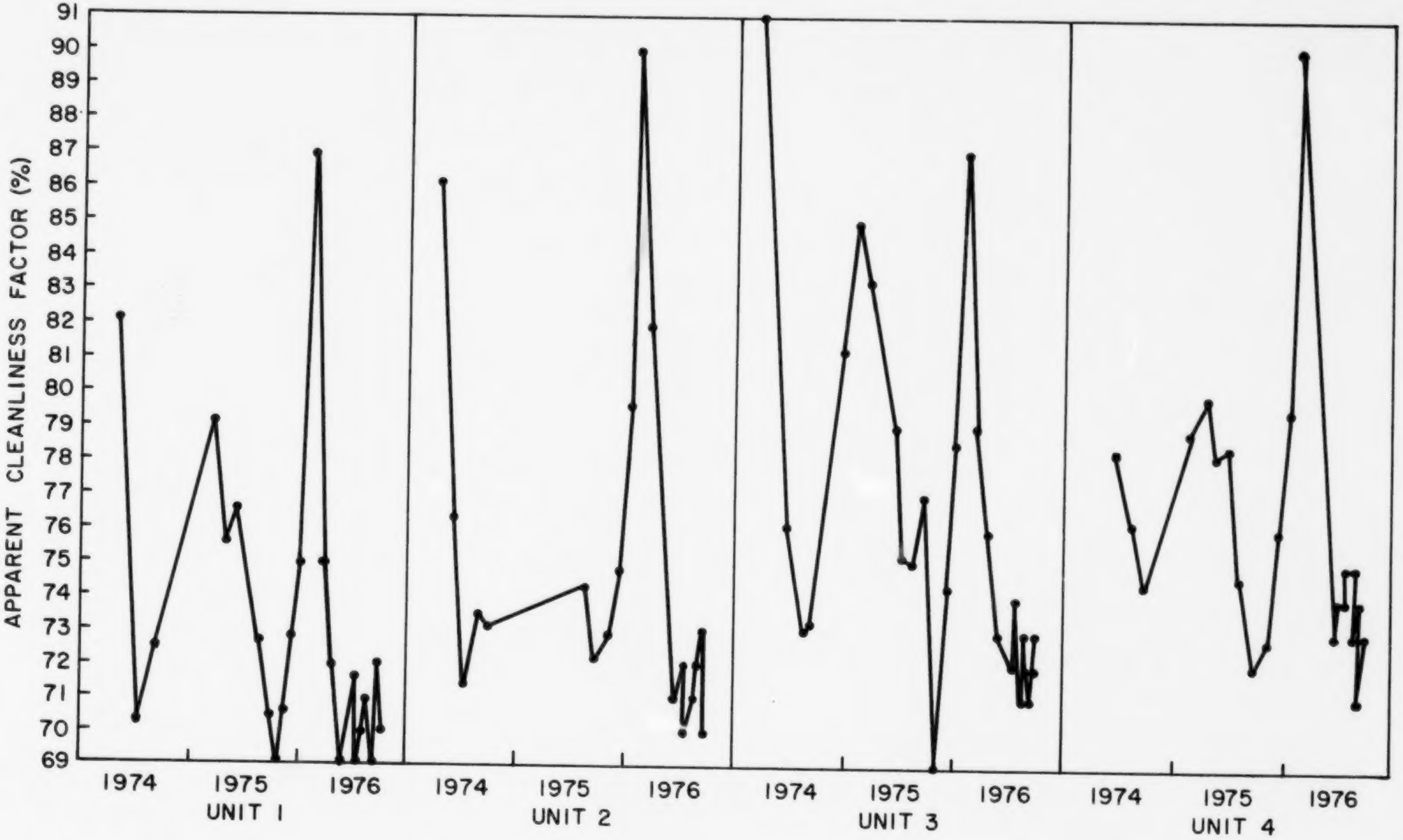

Figure 3. Units 1-4 condenser performance - John Sevier Steam Plant.

Based on this preliminary data, it was recommended that:

1. The free and total residual chlorine measurements be taken at the point of chlorination, the inlet to the condenser, and the outlet of the condenser.
2. Condenser performance tests and chlorine measurements should be taken weekly and together.
3. If the test condensers fall below 70 percent apparent cleanliness factor on five successive measurements or 5 percent below the control condensers' apparent cleanliness factor, then the chlorination rate and/or duration of feed should be increased.
4. The free chlorine concentration at the outlet of the condenser must be carefully measured by the most skilled laboratory analyst.

PHASE I--MAY THROUGH AUGUST 1976

The Approach

The chlorine feed rate and duration of feed at the John Sevier Steam Plant under past operating practices was 6000 lb/24 hrs. per unit at 20 minutes twice per day. After obtaining preliminary test data in March of 1976, the following feed rates and duration of feed were incorporated into a test plan for Phase I:

Unit 1	6000 lb/24 hrs for 2 hrs. once/day
Unit 2	7500 lb/24 hrs for 20 min. twice/day
Unit 3	4500 lb/24 hrs for 20 min. twice/day
Unit 4	6000 lb/24 hrs for 20 min. twice/day

The feed rate used on Unit 1 represented an attempt to measure the effect of increased chlorine duration on condenser cleanliness. The feed rate presented for Unit 2 represented an attempt to measure the effect of increased chlorine concentration on condenser cleanliness. The feed rate used for Unit 3 represented an attempt to measure the effect of decreased chlorine concentration on condenser cleanliness. Unit 4 was the control condenser with the feed rate, duration, and frequency the same as current plant practice.

The Program

TVA initiated intensive sampling of the condenser cooling water on May 11, 1976. The initial sampling attempted on the night of May 11 had to be terminated due to problems with the chlorinator. Because of these problems, testing was not started until May 26. On May 26, water samples were taken at the intake to determine the chlorine demand and its effect on chlorine dosage rates. Samples of chlorinated water were also taken at the inlet and outlet of the condensers for free and total residual chlorine determinations.

It was apparent from the preliminary data that a large variable existed since there was no reasonable correlation of measured total residual chlorine at the injection point and the feed rate of the chlorinator. This phenomenon occurred even when the same feed rate was tested on a different unit. Although other possibilities exist, it was hypothesized that this phenomenon was mainly a result of the feed rate of the chlorinators (i.e., the instrument setting on the chlorinator may not always correlate with what was actually fed since the chlorinators were twenty years old and in poor physical condition). On May 26, the prescribed feed rate of 7500 lbs/24 hrs could not be attained. The maximum feed rate experienced was 7000 lbs/24 hrs. On June 16, only 4500 lbs/24 hrs maximum could be fed to the condensers. This problem existed throughout Phase I testing.

Problems were also experienced with the amperometric titrators. Electrode malfunctions and electronic drift were the main problems.

A sample of the results of field tests from June 9, 1976 through August 19, 1976, may be found in the following pages.* It was noted that the concentration of total residual chlorine obtained at the intake was far below the calculated feed concentration (see Table 3).

During the course of Phase I, we identified several factors that should be taken into account when comparing the data. The factors consist of water quality, the condition of the chlorinator, the condition of the cooling system, the feed rate, and accuracy and precision of the chlorine analysis method. The following data are representative of those obtained during the Phase I study:

1. Chlorine demand data (Table 4).
2. Water quality data (Figure 4).
3. Condenser performance data (Figure 5).
4. A sample of the data for free and total residual chlorine concentrations at the intake, inlet, and outlet of the condenser for Units 1-4 may be found in Table 5 and Figure 6.

An analysis of Phase I data was performed in order to address the following questions:

1. Do we sample the system often enough to get statistically meaningful data?
2. Do we get enough data points during a 20 minute chlorination period to allow reasonable statistical analysis of results?
3. Is there any correlation between feed rate and free and/or total residual chlorine at the outlet of the condenser?
4. Is there any trend in the amount of chlorine consumed through the system for different feed rates and water quality?
5. Is there any correlation between the chlorine demand of the intake water and the free or total residual chlorine at the outlet of the condenser for a given rate?

The data analysis indicated that there are several factors which influence the use of chlorine in the system. Some of these factors are:

1. Chlorine demand of the river water used for condenser cooling water.
2. Chlorine demands of the mixing tank at the chlorinator and the tunnel.

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*A complete summary of all field data may be found in the appendices.

TABLE 3. CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Total Cl_2 Conc. (mg/l)	Intake Measurements TRC (mg/l)
6/9/76	2	6000	113,967	4.38	3.47
	3	4500	99,799	3.75	2.43
	4	6000	124,694	4.00	3.68
6/15/76	1	6000	128,581	3.88	2.14
6/16/76	1	4500	128,581	2.91	2.56
	2	4500	133,390	2.77	2.61
	3	4500	121,317	3.09	2.80
	4	4500	122,466	3.06	2.41
7/7/76	2	7500	138,798	4.50	3.50
	3	4500	139,631	2.68	2.33
	4	6000	129,241	3.86	2.90
7/8/76	1	6000	139,924	3.57	1.76
	2	7500	138,798	4.49	-
	3	4500	139,631	2.68	1.75
	4	6000	129,241	3.86	3.00
7/16/76	1	6000	124,128	4.02	1.92
	2	7500	137,866	4.52	2.60
	3	4500	119,689	3.13	0.91
8/13/76	1	6000	130,245	3.83	1.23
	3	4500	103,227	3.63	1.53
	4	6000	115,352	4.33	2.56
8/19/76	1	6000	139,655	3.58	-
	2	7500	128,108	4.87	-
	3	4500	132,630	2.82	-
	4	6000	130,766	3.82	-

$$\frac{\text{Feed Rate lb/24 hrs.}}{\text{Flow Rate gal/min.}} \times 83.22 = \text{mg/l } Cl_2$$

TABLE 4. CHLORINE DEMAND

1976 Unit 3

Date	Feed Rate (mg/l Cl_2)	10 Min. (mg/l Cl_2)	30 Min. (mg/l Cl_2)
6/9/76	3.75	2.0	2.75
6/16/76	3.09	1.10	1.60
7/7/76	2.68	.98	1.68
7/8/76	2.68	.88	1.48
7/16/76	3.13	1.33	1.93

Date	Feed Rate (mg/l Cl_2)	1 Min. (mg/l Cl_2)	5 Min. (mg/l Cl_2)	10 Min. (mg/l Cl_2)
8/13/76	3.63	.43	.73	1.03
8/19/76	2.82	.30	.65	1.35

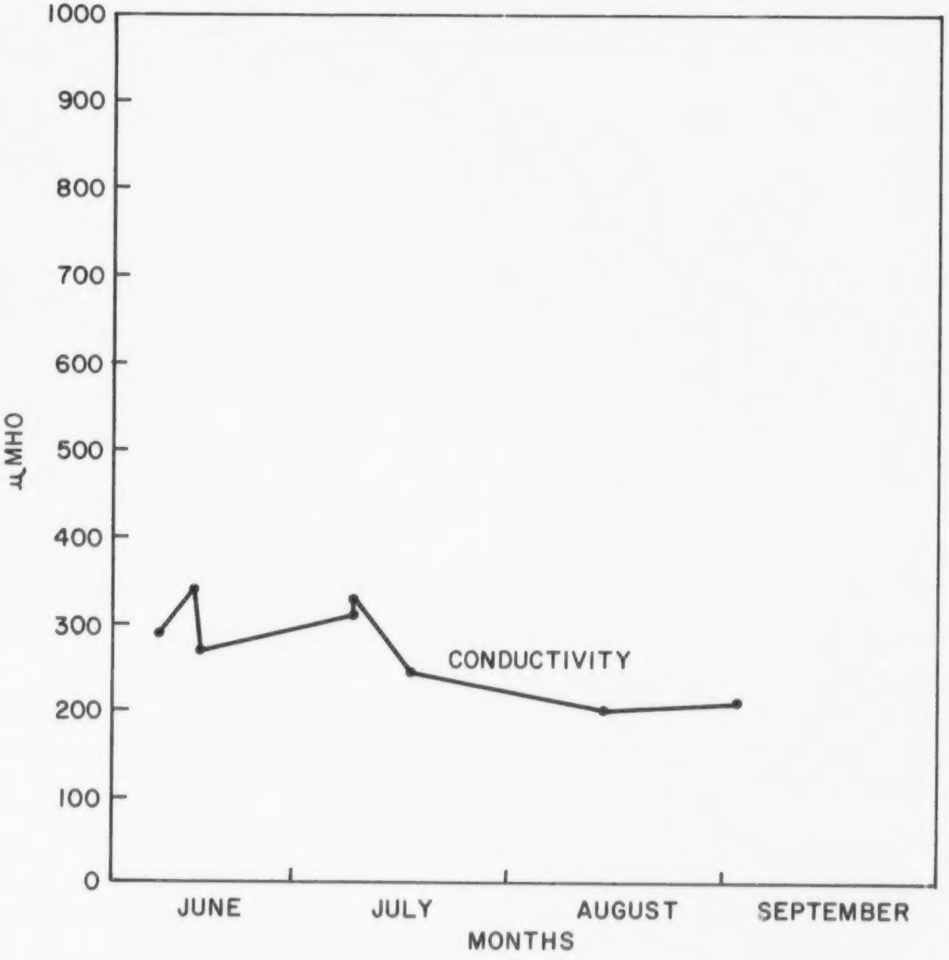


Figure 4. 1976 water quality data.

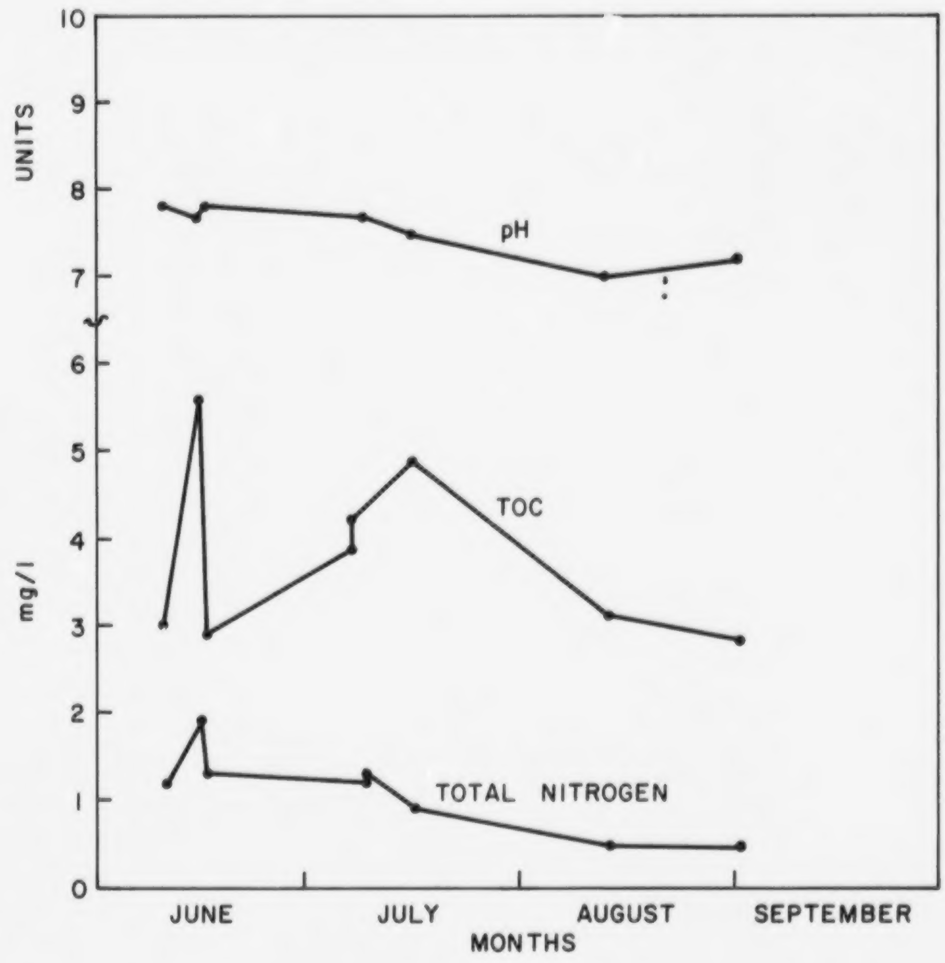


Figure 4. (continued)

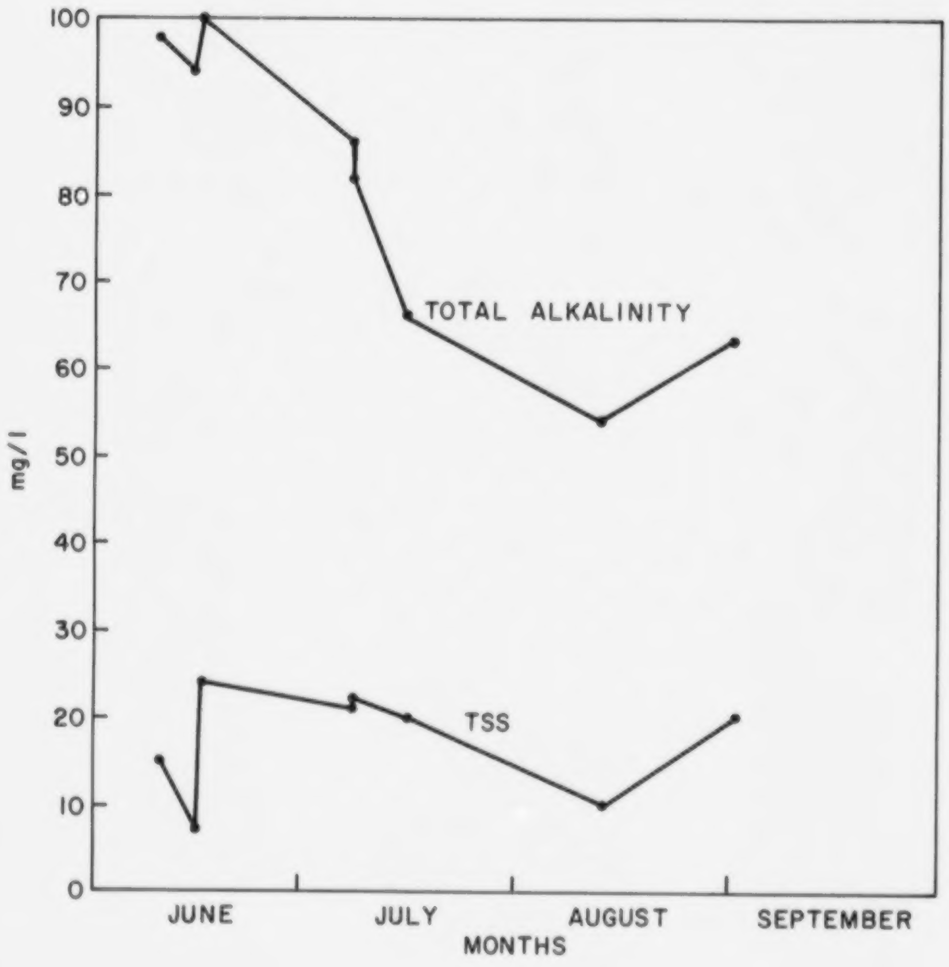


Figure 4. (continued)

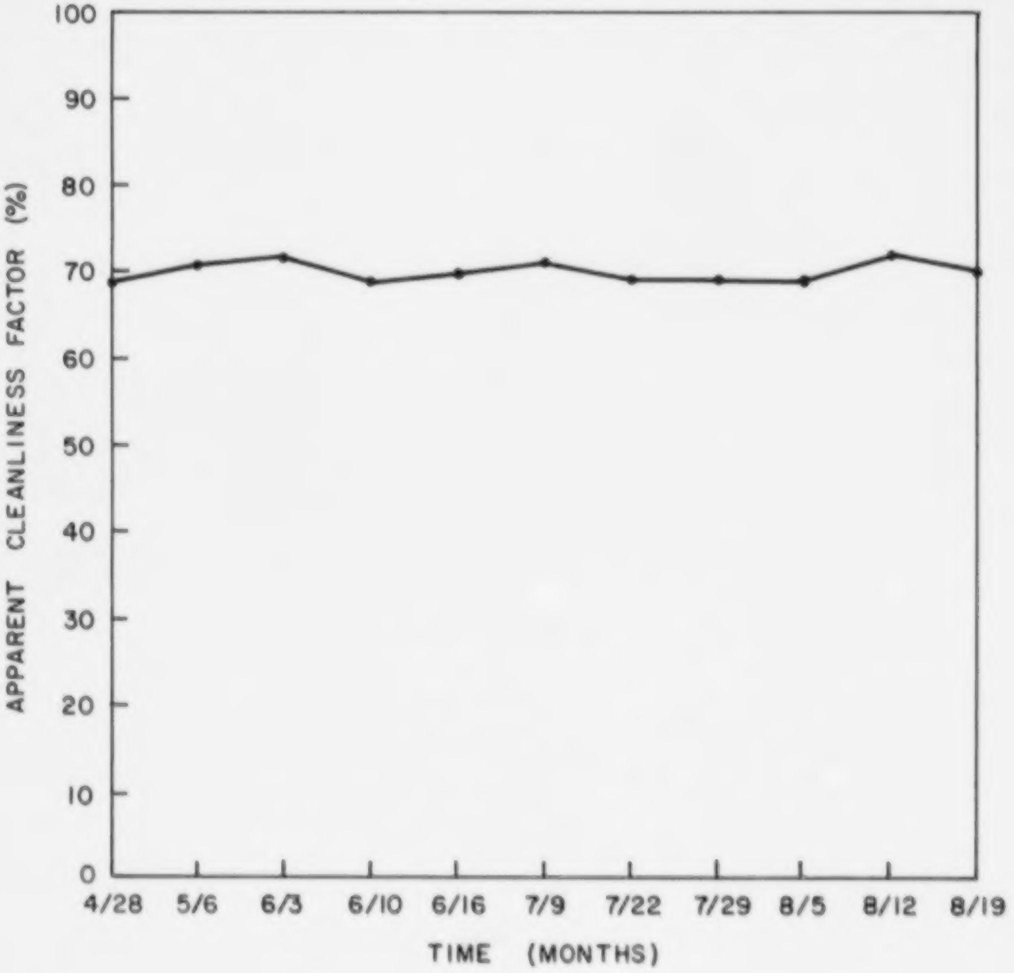


Figure 5. Unit I 1976 record of apparent cleanliness factor.

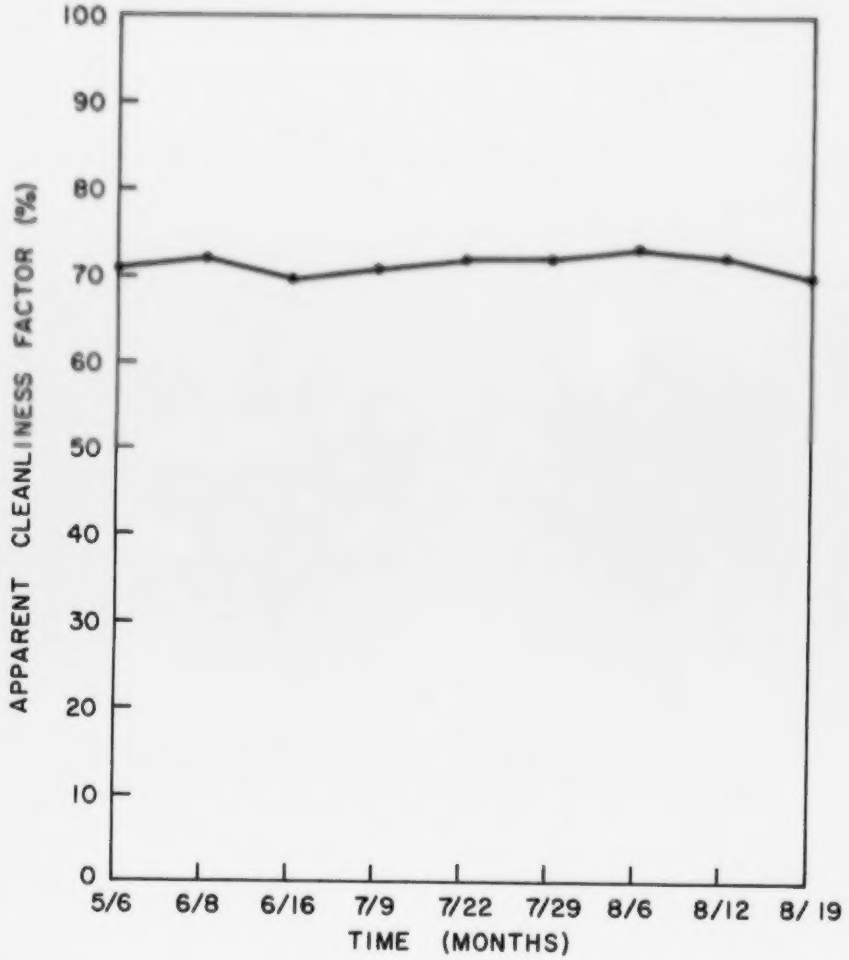


Figure 5. (continued) Unit 2 1976 record of apparent cleanliness factor.

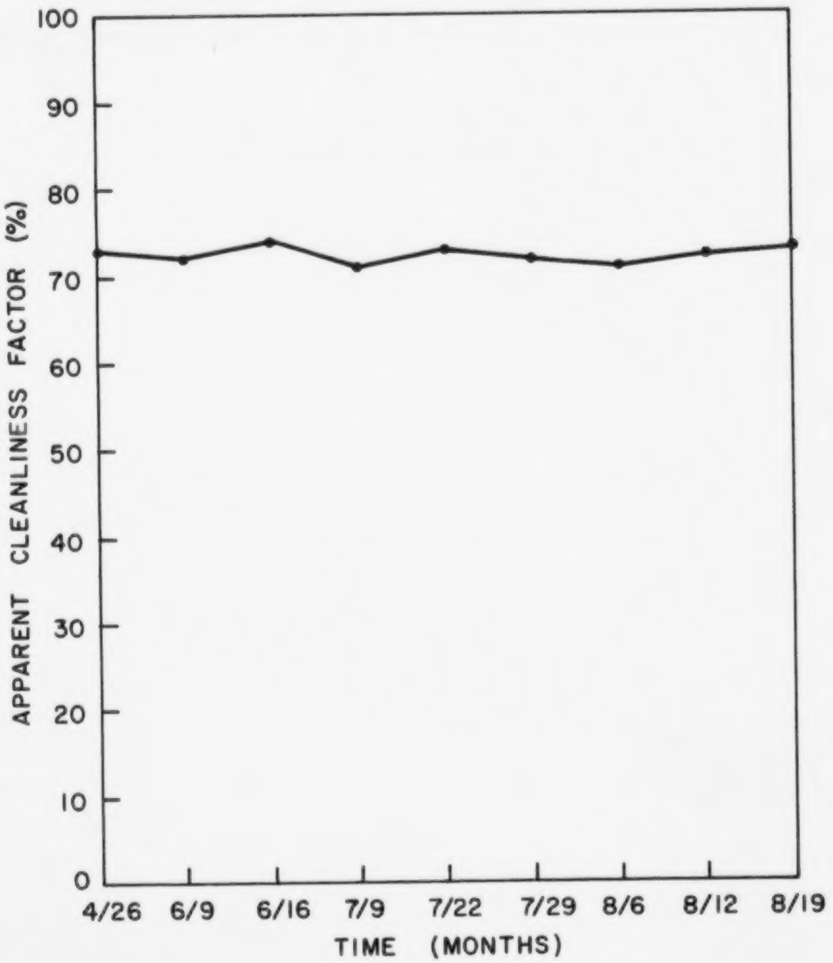


Figure 5. (continued) Unit 3 1976 record of apparent cleanliness factor.

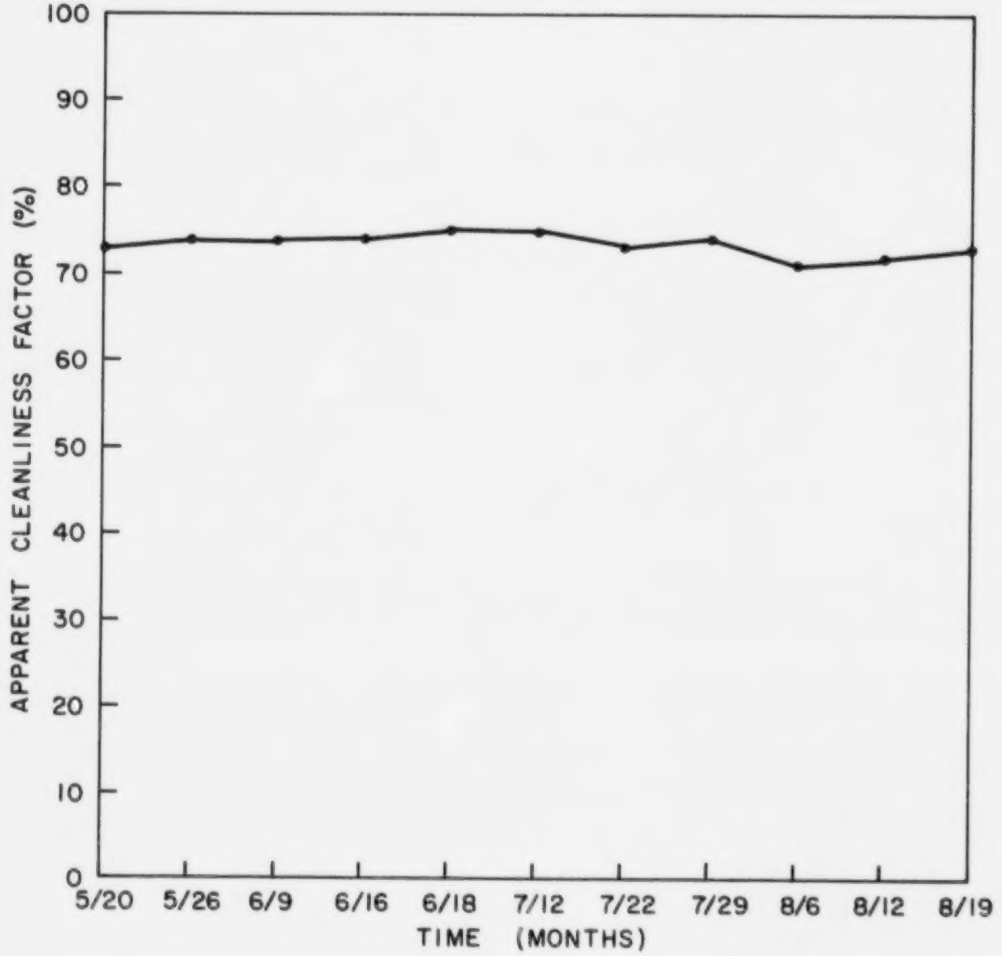


Figure 5. (continued) Unit 4 1976 record of apparent cleanliness factor.

TABLE 5

CHLORINE STUDIES DATA SHEET

UNIT 2

FEED RATE 6,000 lbs/day

LENGTH OF FEED 2x20 min

DATE June 9, 1976

	INLET			OUTLET			INTAKE			DISCHARGE	
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
10:05	.5	2.0	10:02	-	0.7	10:01	1.05	2.41			
10:10	.53	1.7	10:05	1.3	1.7	10:04	2.91	3.72			
10:14	.65	1.6	10:09	.92	1.56	10:08	2.57	3.07			
10:16	.65	1.8	10:12	.67	1.68	10:11	2.53	3.31			
10:22	.7	2.4	10:17	1.12	1.25	10:14	2.23	3.45			
10:26	.1	.2	10:20	?	1.07	10:17	2.69	3.47			
			10:24	.65	1.00						
			10:27	.5	0.0						

DEMAND DATA

PH 7.5
TEMP 21 °C
1 MIN. CLORINE DEMAND
5 MIN. CLORINE DEMAND
10 MIN. CLORINE DEMAND

FLOW RATE

113,967 gpm
APPARENT CLEANLINESS FACTOR

WATER QUALITY

NH_3 .26
NO_2, NO_3 .78
ORG. N .13
COND 290
TSS 15
TOC 3.0
TOT. ALK. 98

TABLE 5 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 3

FEED RATE 4,500 lbs/day

LENGTH OF FEED 2x20 min

DATE June 9, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
11:04	1.0	2.0	11:00	-	1.58	11:01	1.34	2.43			
11:08	.7	1.5	11:04	1.1	1.56	11:04	1.14	2.27			
11:13	.6	1.85	11:10	.85	1.16	11:07	2.36	2.85			
11:16	.8	1.9	11:15	.61	.95	11:11	1.54	2.28			
11:22	.15	.15	11:19	.62	1.08	11:14	1.51	2.57			
11:24	0.0	0.0	11:23	.42	0.0	11:17	1.97	2.39			

DEMAND DATA

PH 7.5
TEMP 21°C
1 MIN. CLORINE DEMAND
5 MIN. CLORINE DEMAND
10 MIN. CLORINE DEMAND

FLOW RATE
99,799 gpm

APPARENT CLEANLINESS
FACTOR

WATER QUALITY

NH_3 .26
NO_2, NO_3 .78
ORG. N .13
COND. 290
TSS 15
TOC 3.0
TOT. ALK. 98

TABLE 5 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 4 FEED RATE 6,000 lbs/day LENGTH OF FEED 2x20 min DATE June 9, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
12:05	.55	1.6	12:04	-	1.51	12:05	1.97	4.02			
12:08	.8	1.45	12:07	1.19	1.51	12:07	2.30	3.87			
12:12	.65	1.75	12:11	.73	1.23	12:12	2.24	3.52			
12:17	.65	2.0	12:15	.75	1.24	12:16	2.47	3.68			
12:22	.85	2.0	12:19	.78	1.15						
12:24	1.3	0.0	12:23	.7	1.07						
			12:26	.8	1.12						

DEMAND DATA

PH 7.5
TEMP 21°C
1 MIN. CLORINE DEMAND ____
5 MIN. CLORINE DEMAND ____
10 MIN. CLORINE DEMAND ____

FLOW RATE

124,694 gpm

APPARENT CLEANLINESS FACTOR ____

WATER QUALITY

NH_3 .26
NO_2, NO_3 .78
ORG. N .13
COND 290
TSS 15
TOC 3.0
TOT. ALK. 98

TABLE 5 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 1 FEED RATE 6,000 lbs/day LENGTH OF FEED 1x2 hrs DATE June 15, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
9:09	1.07	1.54	8:55	-	.94	8:53	0.0	0.0			
9:14	1.24	1.72	8:59	.09	-	8:54	0.0	.85			
9:18	1.54	1.73	9:02	0.0	1.32	8:57	.43	1.34			
9:21	1.46	1.71	9:07	.09	1.39	9:01	.48	.76			
9:25	1.72	1.72	9:12	.1	1.52	9:06	.79	2.34			
9:30	1.32	2.03	9:17	.21	1.46	9:10	.32	.72			
9:35	1.32	2.6	9:21	.1	.9	9:13	.97	2.14			
9:40	1.1	1.1	9:25	.12	1.43	9:17	.27	.87			
9:44	1.21	2.61	9:30	.15	1.80	9:28	1.42	3.05			
9:49	1.4	2.59	9:37	.38	1.27	9:32	.43	1.35			
9:54	1.73	2.5	9:42	.21	1.00	9:44	2.23	5.52			
			9:45	.32	2.37	9:48	1.43	2.98			
			9:50	.30	2.38	9:51	2.32	4.94			
			9:55	~.5	2.39						
			10:00	.13	0.0						

DEMAND DATA

PH 7.5
TEMP 27.2°C
1 MIN CLORINE DEMAND
5 MIN. CLORINE DEMAND
10 MIN. CLORINE DEMAND

FLOW RATE

128,581 gpm

APPARENT CLEANLINESS FACTOR — —

WATER QUALITY

NH_3 .5
NO_2, NO_3 .97
ORG. N .43
COND. 340
TSS 7
TOC 2.9
TOT. ALK. 94

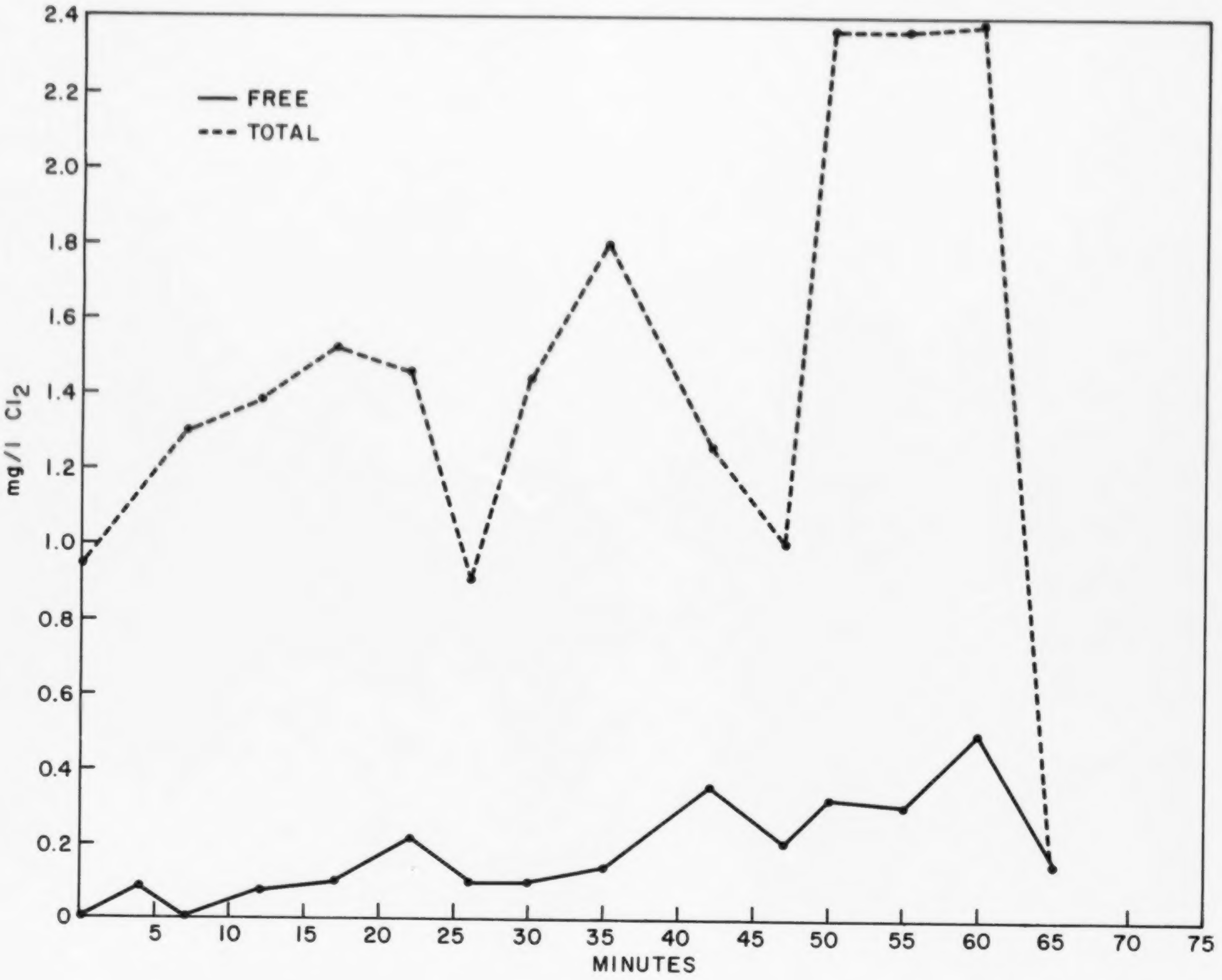


Figure 6. Unit I free vs. total residual measurements (outlet).

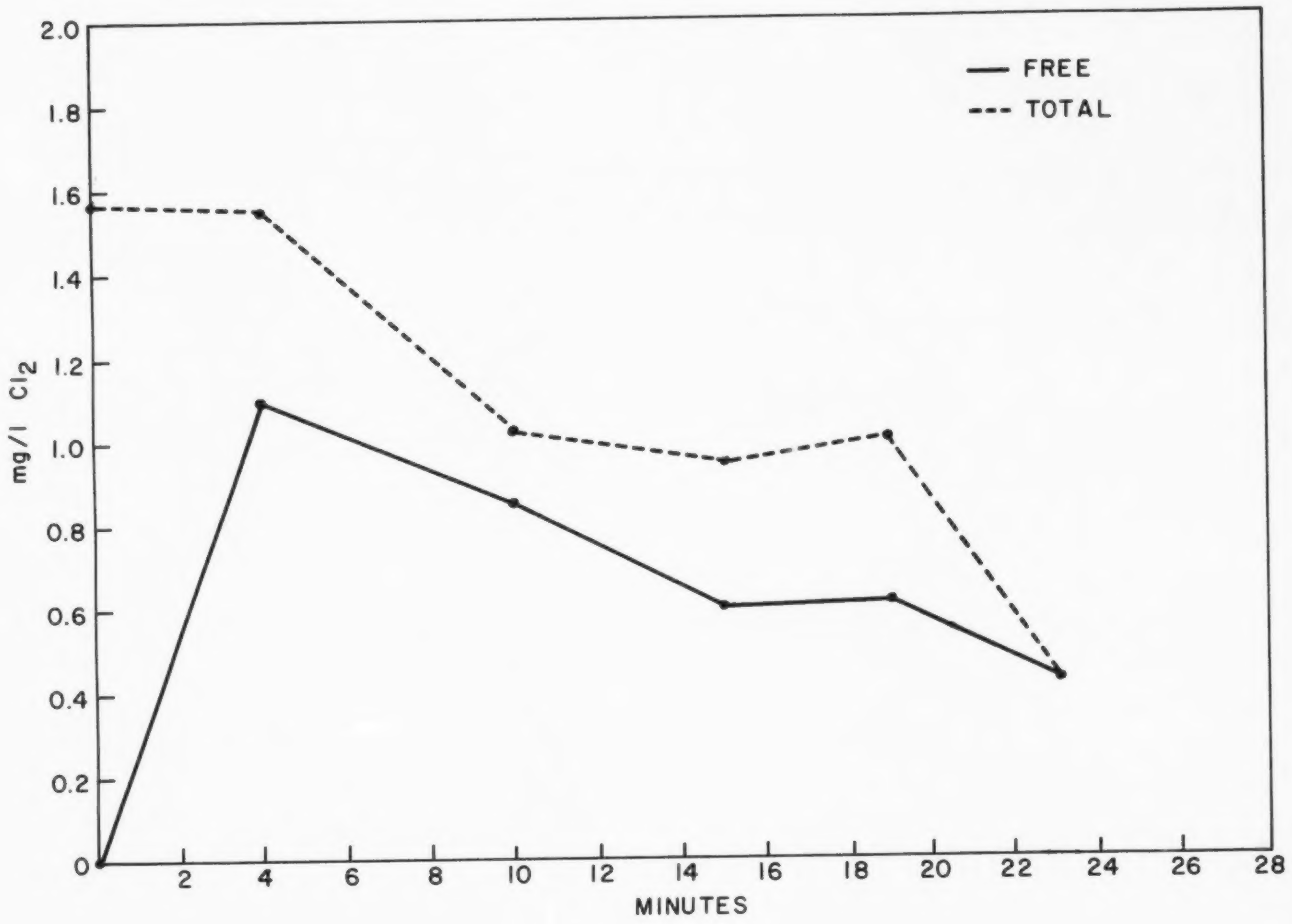


Figure 6. (continued) Unit 3 free vs. total residual measurements (outlet).

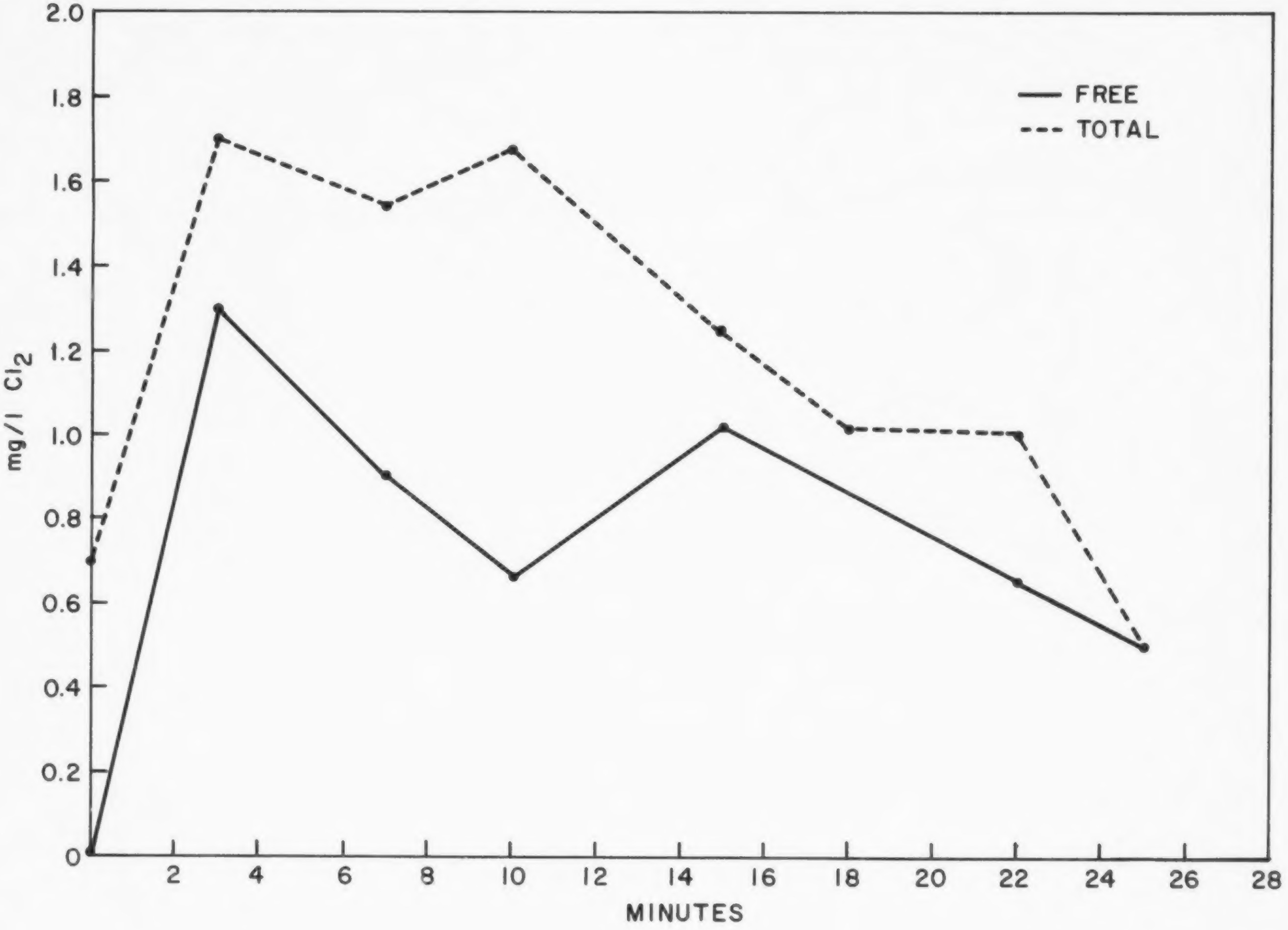


Figure 6. (continued) Unit 2 free vs. total residual measurements (outlet).

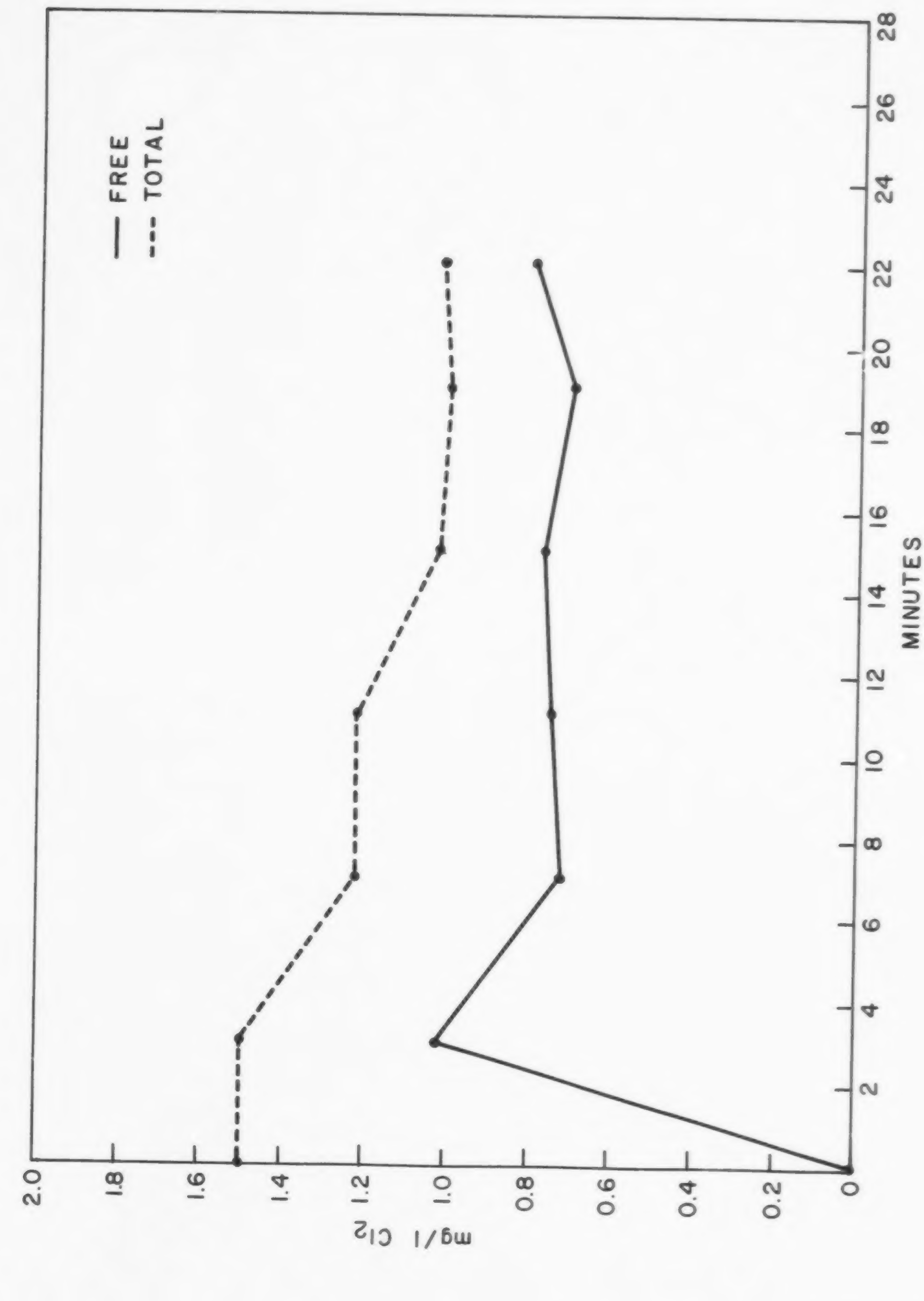


Figure 6. (continued) Unit 4 free vs. total residual measurements (outlet).

3. Chlorine demand of the condenser.

4. Flow rate of the condenser circulating cooling water.

Chlorine demand data was collected on the river water at the intake to the condenser cooling water system from May 27, 1976, to August 19, 1976. Ten and thirty minute chlorine demand curves were obtained for all test dates except for August 13 and 19. Samples taken on these respective dates had chlorine demand curves for 1-, 5-, and 10-minute intervals. Chlorine demands are shown in Table 4.

During this period the flow rates through the system varied from approximately 100,000 gal/min to 131,000 gal/min. Based upon the length of the tunnels (685 feet), the diameter of each tunnel (8 ft.), the number of tunnels (1), and an average flow rate of 120,000 gal/min, it takes approximately 2.2 minutes for water to arrive at the inlet to the condenser after passing the chlorine injection point.

The chlorine demand data for the river water indicates a significant demand at 5 and 10 minutes. The difference between the respective measured value for total residual chlorine at the inlet to the condenser and at the intake has indicated that a chlorine demand exists within the system and may be caused by any one or all of the following: demand of the water as a function of time, and the chlorine demand of the tunnels and/or the mixing tank at the chlorinator injection point.

An accurate comparison of the chlorine demand of the water for samples HB2-7 with the difference in the feed concentration and the field measurement at the inlet of the condenser was not possible due to the time of reaction (2.2 minutes) from the chlorine injection to the inlet of the condenser. The chlorine demand for the water during this narrow period of time was not examined in the laboratory during Phase I except during the last two test days of August 13 and 19, 1976. Although the values could be calculated by extrapolating a plot of chlorine demand versus time, we believe that to assume the demand to be linear from 10 minutes to zero would be an error.

Chlorine concentration measurements at the outlet of the intake pump suction well were consistently less than the calculated chlorine feed rate. This difference has been attributed to the mixing tank, to the reaction of chlorine with water, and to the inability of the old chlorinator to maintain a set feed rate. The difference due to the mixing tank varied greatly from March of 1976, when the demand associated with the mixing tank was approximately 10 percent of the calculated input, to August of 1976, when the demand increased to approximately 40 percent of the calculated input (see Table 3).

During the test period of May through August, the total residual chlorine at the inlet of the condenser was generally 50 percent of the total residual chlorine measured at the intake. The free residual chlorine at the inlet to the condenser was approximately 70 percent of the total chlorine measured at the inlet. Furthermore, the outlet free residual chlorine was approximately 0.5 mg/l less than the inlet free residual chlorine and was to some extent independent of chlorination time and feed rate. This change of free residual chlorine across the condenser will be called "condenser demand" in this report.

The limiting factor for maintaining a high apparent cleanliness factor during the summer months appears to be the short time (5 seconds) for the reaction of free chlorine in the condenser. Therefore, on July 8, 1976, Unit 1 was chlorinated for one hour instead of the usual 20 minutes in order to determine if the free residual chlorine at the outlet of the condenser would change with a longer period of reaction. The outlet free chlorine measurements showed a consistent 0.5 mg/l difference for the total hour. This was similar to the inlet to outlet free chlorine measurement experienced previously for 20 minute chlorination periods. Thus, at a feed rate of 6000 lb/24 hrs, periods of chlorination longer than 20 minutes would probably not be advantageous.

Based on this information and an analysis of the data, recommendations for Phase II studies at John Sevier Steam Plan were established. They were:

1. Chlorine demand tests on the river water should be performed at 1-, 3-, and 5-minute intervals if possible.

2. Subsequent chlorination rates should be at 6000 lb/24 hrs at two 20-minute periods for a control basis and rates of 4500 and 3000 lbs/24 hrs on two other units.

3. Longer chlorination periods (2 hours) at 1500 lb/24 hrs should be tested on the fourth unit.

4. The most skilled laboratory analysts should be used to take measurements.

PHASE II - APRIL THROUGH SEPTEMBER 1977

The Approach

On April 19, 1977, a meeting was held at the John Sevier Steam Plant to discuss the past chlorination tests (Phase I) and the Phase II chlorination tests at the plant.

The new chlorinator, purchased by the plant, was in service at this time. However, due to high back pressure in the vacuum water line, water leaked into the gas flow metering system. Thus, the chlorinator went out of service the second week in May 1977. As a result, the old chlorinator was used during the Phase II tests.

Since data from Phase I indicated that the "condenser demand" (i.e., inlet to outlet change in free residual chlorine) was about 0.5 mg/l free chlorine, the approach for Phase II was to maintain a free chlorine residual of 0.5 mg/l at the inlet to the condenser. During Phase I it was found that a chlorine feed rate of 4500 lbs/24 hrs would maintain approximately 0.5 mg/l free chlorine residual at the inlet to the condenser assuming similar water quality. Thus, a feed rate of 4500 lbs/24 hrs was fed to all units with only the frequency and length of feed changed. The following test conditions were established for Phase II:

Unit	Feed Rate lbs/24 hrs	Frequency/Day	Chlorine Feed Time in Minutes
Unit 1	4500	2	60
Unit 2	4500	2	30
Unit 3	4500	3	20
Unit 4	4500	6	10

The long chlorination period on Unit 1 was to determine if the chlorine could satisfy the "condenser demand." This would result in the free residual chlorine at the inlet and outlet being equal within experimental error.

Test procedures consisted of performing condenser performance tests every two weeks and measuring flow rates weekly. Tests would begin May 6, 1977, and continued each week throughout the summer. If there was no appreciable change in the condenser performance of each unit and the free and total chlorine residuals were higher than 0.1 to 0.2 mg/l FRC (see Section 4 for explanation), then the feed rate was lowered accordingly after at least an initial two months at a feed rate of 4500 lbs/24 hrs.

The Program

Tests at John Sevier during Phase II began as scheduled on May 6, 1977. Weekly tests continued during May, June, July, August, and September 1977. Each week, samples of the chlorinated condenser cooling water were taken at the inlet and outlet of each condenser. During each weekly test period, water samples were taken at the intake and analyses were performed by TVA's Laboratory Branch to determine the following parameters: (1) pH, (2) temperature, (3) alkalinity, (4) chlorine demand--1, 5, and 10 minutes, (5) total organic carbon, (6) conductivity, (7) ammonia as N, (8) total suspended solids, (9) nitrates plus nitrites as N, and (10) organic nitrogen as N. A plot of some of the above parameters as a function of time may be found in Appendix B. Chlorine demand data for 1977 is presented in Table 6.

Amperometric titration[14] was the method used on all test days. On nine of the test dates, the DPD method was used on Unit 1 in addition to the amperometric method (for a comparison of the two methods see Appendix F). Since both methods are identified in the Federal Register by EPA as standard analytical methods for collecting residual chlorine data, the use of both methods would allow a field comparison of the reliability, consistency, and accuracy of the two methods. Problems of drift and inconsistent results were experienced in the measurement of free and total residual chlorine using the amperometric titrators. The problems were improved by cleaning the electrodes with distilled water between samples and with a nonchlorinated detergent every two weeks, 24 hour acclimating the electrodes to chlorine, and titrating excess phenylarsine oxide into solutions after each sample was analyzed.

The electrodes are susceptable to a thin film forming on the surface of the platinum plates when left in or out of water. This film will cause drift and unusual readings. In addition, after running one sample for free and total residual chlorine, the iodide reagent tends to form a film on the electrode surfaces. This contributes to the drift and unusual measurements on subsequent readings. Frequent electrode cleaning reduces the film formation of the water constituents on the platinum plates. It was also recommended by the Fischer and Porter Central Laboratories in Warminster, Pennsylvania, that by titrating excess phenylarsine oxide into the solution, excess iodine is prohibited from forming a film on the electrodes. The 24-hour acclimation of the electrodes is normal procedure when using sensitive potentiometric equipment.

The feed rate of the chlorinator remained at 4500 lb/24 hrs through three months. A complete chart of feed rates and initial chlorine concentrations may be found in Table 7. Condenser performance tests were performed biweekly in order to monitor the changes in the apparent cleanliness factor. The apparent cleanliness factor (ACF) data and the free and total residual chlorine levels were used as a basis for formulating any changes in the feed rate. When the ACF data indicated a sudden decrease, the chlorine feed rate was increased; and when the free residual chlorine suddenly increased, the feed rate was reduced.

In these tests the condenser performances were evaluated on the basis of the apparent cleanliness factor (ACF). It is not possible to directly compare the apparent cleanliness factor of one year to the next without considering when each condenser was manually brush cleaned, and other operational data. After each brush cleaning, the cleanliness factor ranges from 80-85 percent. After cleaning, there is a sharp ACF decline in the spring and then a further gradual decline through the summer. In order to determine if the lower feed rates of 1977 resulted in any significant change in ACF as compared with 1976, the time interval between each manual cleaning of the tubes was considered in the analysis. For a comparison of the ACF for 1976 with the ACF for 1977, see Figure 7 and Table 8.

TABLE 6. 1977 CHLORINE DEMAND

UNIT 4

Date	*Feed Rate in mg/l	1 Min.	5 Min.	10 Min.
5/6/77	2.48	0.18	0.78	-
5/12/77	2.75	0.64	0.50	0.79
5/20/77	2.96	0.19	0.58	0.79
5/27/77	2.92	0.44	0.97	1.40
6/3/77	2.86	0.41	0.91	1.31
6/10/77	2.88	0.18	0.58	0.78
6/17/77	2.89	0.30	0.59	1.14
6/24/77	2.93	0.38	0.97	1.07
6/30/77	3.03	0.51	0.82	1.21
7/6/77	2.97	0.59	0.79	1.67
7/13/77	3.07	0.51	0.85	1.22
7/20/77	3.01	0.29	0.69	1.00
7/27/77	3.20	0.70	1.25	1.46
8/18/77	2.95	0.68	1.07	1.39
9/2/77	1.63	0.30	0.41	0.54
9/9/77	1.67	0.20	0.37	0.60
9/16/77	1.65	0.29	0.47	0.56
9/23/77	1.68	0.27	0.38	0.61

*See Table 7

TABLE 7. 1977 CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/Min.)	Cl_2 Concentration (mg/l)
5/6/77	1	4500	154,000	2.43
	3	4500	141,000	2.66
	4	4500	151,000	2.48
5/12/77	1	4500	135,872	2.76
	3	4500	114,000	3.28
	4	4500	136,425	2.75
5/20/77	1	4500	140,007	2.67
	2	4500	122,911	3.05
	3	4500	131,289	2.85
	4	4500	126,583	2.96
5/27/77	1	4500	137,765	2.72
	2	4500	128,856	2.91
	3	4500	132,873	2.82
	4	4500	128,117	2.92
6/3/77	1	4500	137,591	2.72
	2	4500	125,638	2.98
	3	4500	134,127	2.79
	4	4500	130,984	2.86
6/10/77	1	4500	137,609	2.72
	2	4500	110,547	3.39
	3	4500	133,895	2.80
	4	4500	129,926	2.88
6/17/77	1	4500	138,196	2.71
	2	4500	138,243	2.71
	3	4500	133,404	2.81
	4	4500	129,732	2.89
6/24/77	2	4500	136,154	2.75
	3	4500	137,242	2.73
	4	4500	127,881	2.93
6/30/77	1	4500	140,402	2.68
	2	4500	137,322	2.73
	3	4500	133,030	2.82
	4	4500	123,675	3.03
7/6/77	1	4500	139,381	2.69
	2	4500	140,354	2.67
	4	4500	125,952	2.97
7/13/77	1	4500	135,885	2.76
	2	4500	135,287	2.77
	3	4500	132,145	2.83
	4	4500	122,053	3.07

Continued

TABLE 7 (Continued)

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/Min.)	Cl_2 Concentration (mg/l)
7/20/77	1	4500	137,828	2.72
	2	4500	133,534	2.80
	3	4500	131,285	2.85
	4	4500	122,505	3.01
7/27/77	1	3000	136,518	1.83
	2	4500	136,904	2.74
	4	4500	117,125	3.20
8/18/77	1	4500	135,131	2.77
	3	4500	132,390	2.83
	4	4500	126,904	2.95
8/25/77	1	2500	132,934	1.56
	2	3000	130,492	1.91
9/2/77	1	2500	130,785	1.59
	2	2500	134,564	1.55
	3	2500	125,908	1.65
	4	2500	127,631	1.63
9/9/77	1	2500	125,812	1.65
	2	2500	135,583	1.53
	3	2500	122,450	1.70
	4	2500	124,760	1.67
9/16/77	1	1500	124,049	1.01
	2	2500	134,233	1.55
	3	2500	121,183	1.72
	4	2500	126,038	1.65
9/23/77	1	1500	124,200	1.01
	2	2500	131,287	1.58
	3	2500	117,328	1.77
	4	2500	123,407	1.68

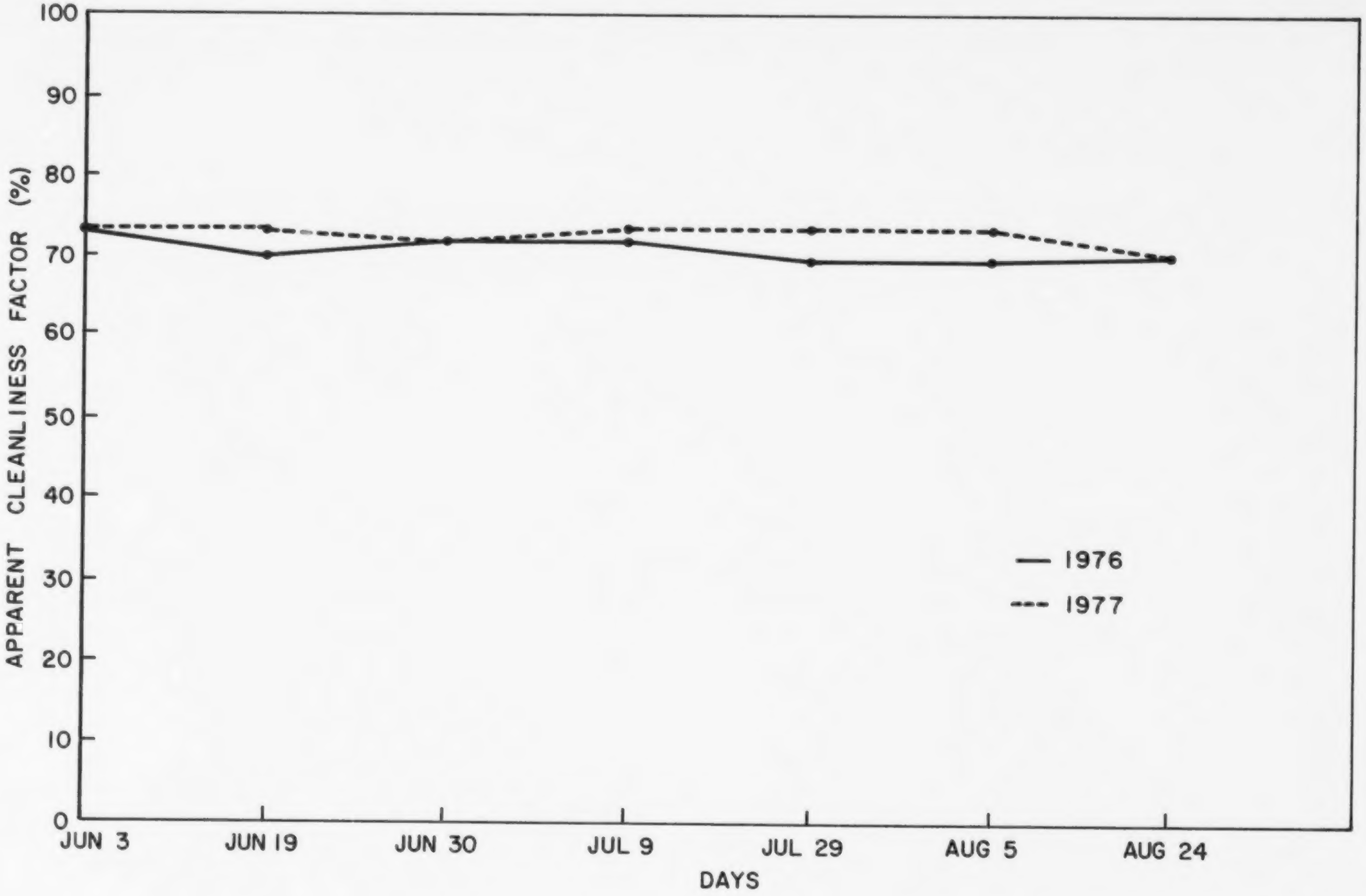


Figure 7. Unit 1 1976 vs. 1977 apparent cleanliness factor.

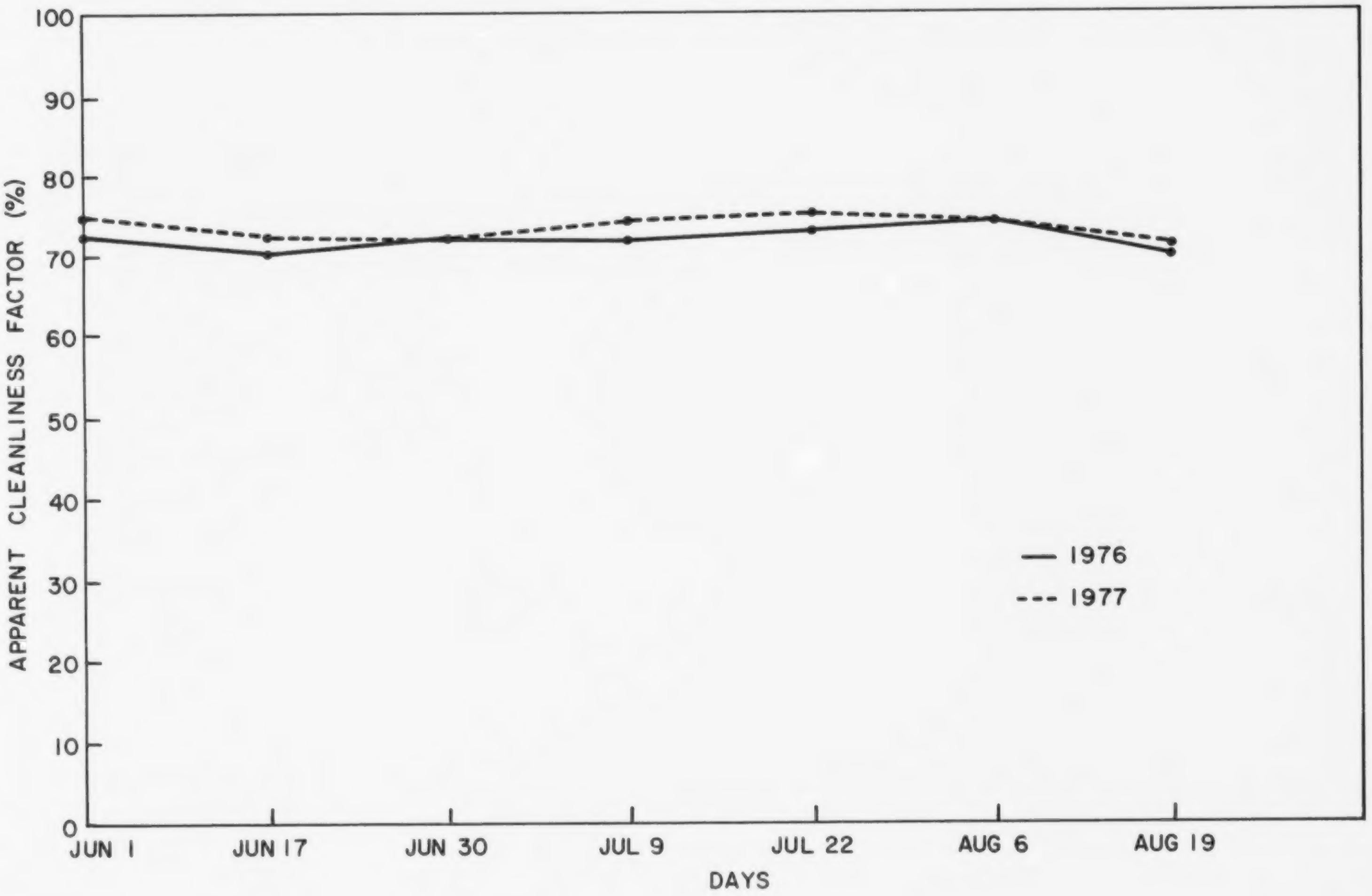


Figure 7. (continued) Unit 2 1976 vs. 1977 apparent cleanliness factor.

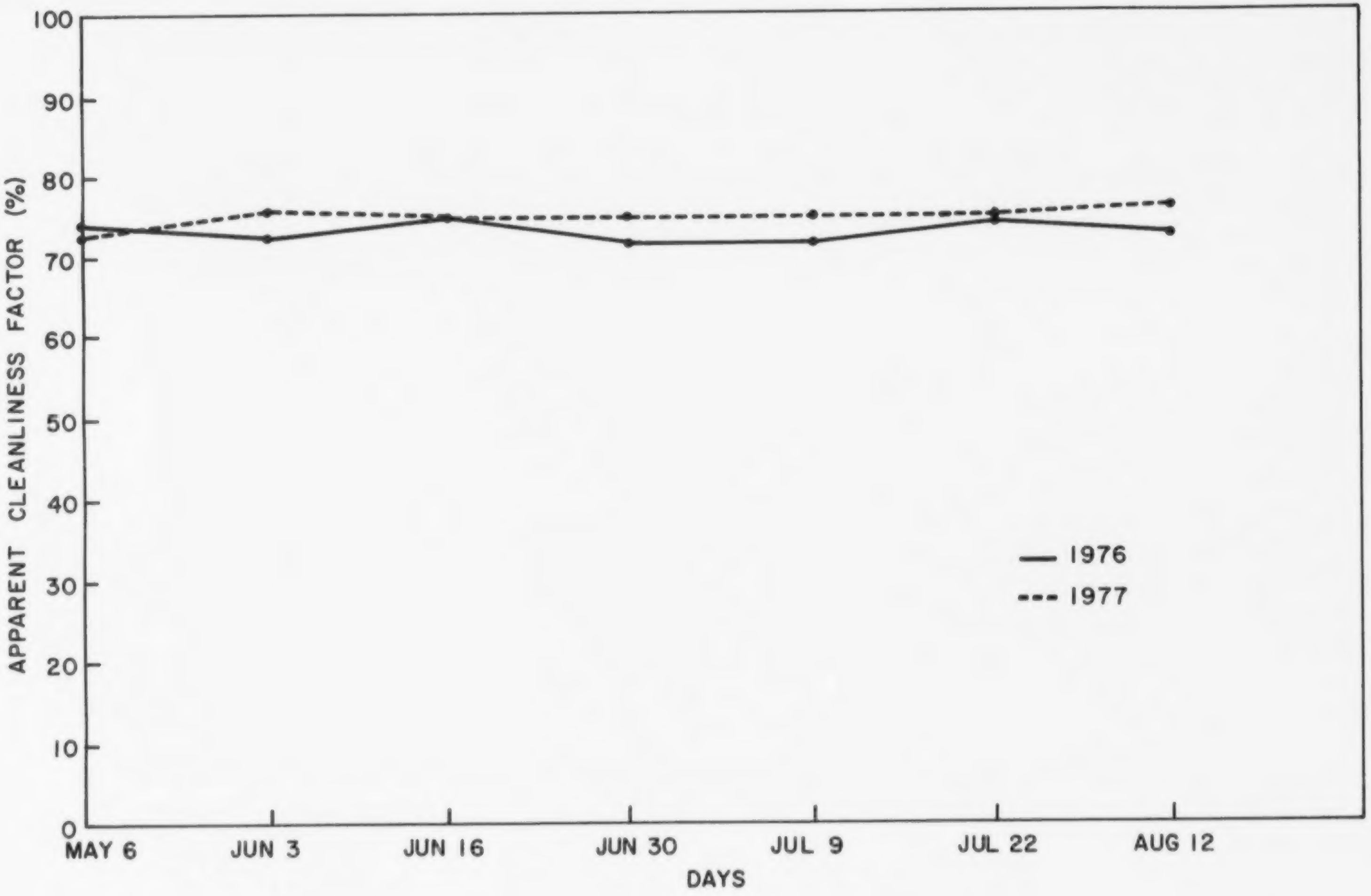


Figure 7. (continued) Unit 3 1976 vs. 1977 apparent cleanliness factor.

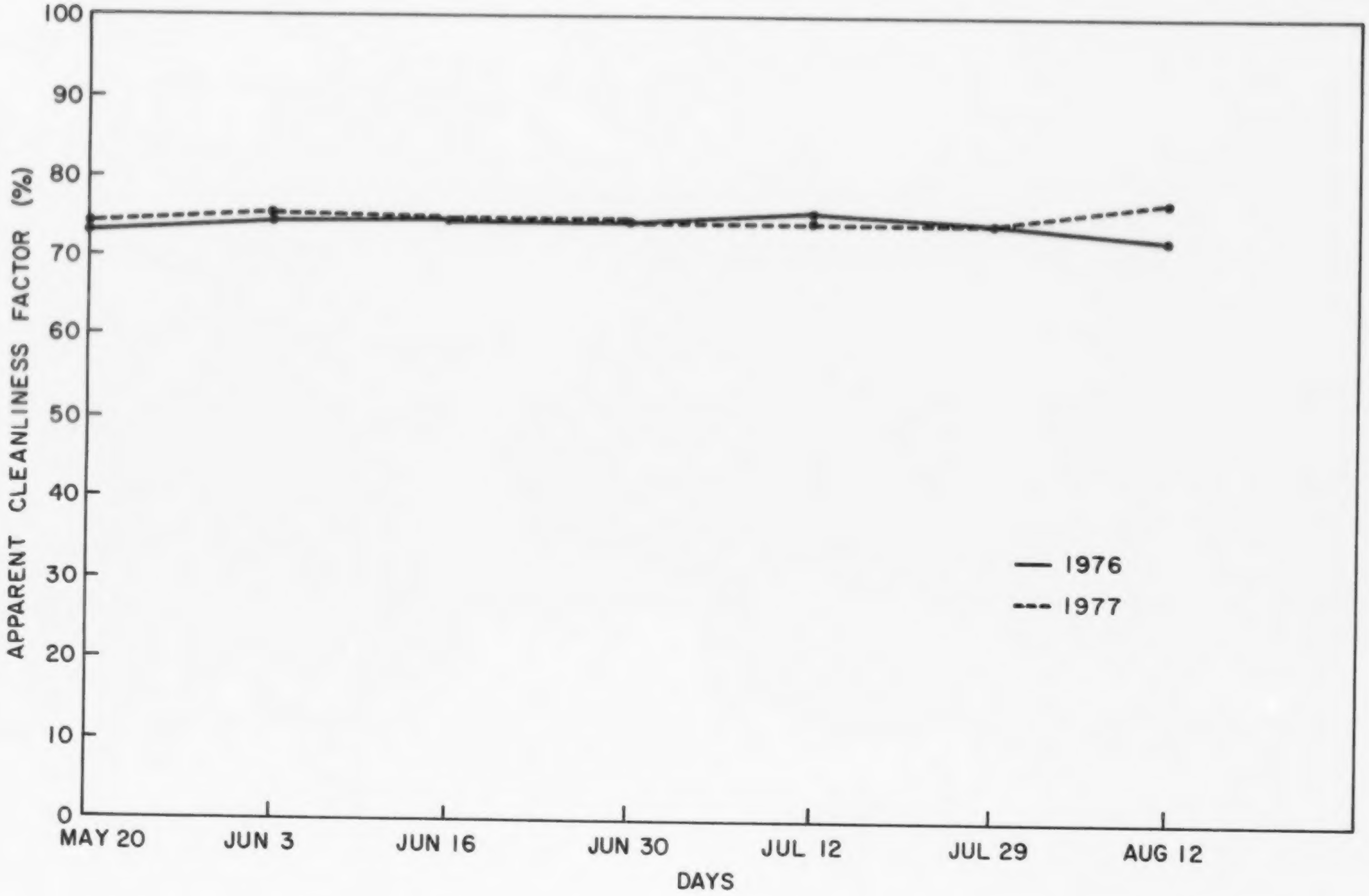


Figure 7. (continued) Unit 4 1976 vs. 1977 apparent cleanliness factor.

TABLE 8. DATES OF CONDENSER CLEANING

UNIT 1

Date (1976)	Nature of Cleaning	Date (1977)	Nature of Cleaning
June 10	Tubes	June 23	Tube Sheet
June 20	Tubes		
June 26	Tubes		
June 27	Tubes		
July 3	Tube Sheet		
August 1	Tube Sheet		
August 15	Tubes		

UNIT 2

June 17	Tubes	May 5-6	Tube Sheet
June 23	Tubes		
June 28	Tubes		
July 1	Tubes		
July 2	Tubes		

UNIT 3

June 15	Tubes	June 8	Tube Sheet
July 3	Tubes	July 24	Tube Sheet
July 4	Tubes	August 15	Tube Sheet
July 17	Tube Sheet		
August 13	Tubes		

UNIT 4

May 25	Tube Sheet	May 21	Tube Sheet
June 19	Tubes	June 6	Tube Sheet
June 21	Tubes		
July 3	Tube Sheet	December 21	Tubes
August 1	Tube Sheet		
August 14	Tubes		

After examination of the data collected in May, June, and most of July, the feed rate was reduced to 3000 lbs/24 hrs on July 22, 1977. The justification for such reduction was that higher than necessary levels of free and total residual chlorine were measured at the inlet and outlet of the condensers and the condenser apparent cleanliness factor was the same or better than it was during the Phase I tests in the summer of 1976, and during 1974 and 1975. It was also noted that the condenser demand was not 0.5 mg/l as found in Phase I, but rather 0.3 mg/l. This discovery was primarily due to an increase in samples and better measuring techniques. However, the chlorine feed rate was not reduced until the end of July to ensure that we had found an operable level which would keep the condensers relatively clean during periods when the inlet water temperature reached extreme conditions (80°-82°F). At these temperatures there is stronger propensity for biological fouling. It was noted from Phase I tests (1976) that as the inlet water temperature increased, there was a noted corresponding increase in total residual chlorine consumed. A comparison of the inlet water temperatures of 1976 and 1977 may be found in Appendix B.

On August 25, 1977, test results for free residual chlorine at the outlet of the condensers and the condenser performance records of each unit indicated further reductions in the chlorine feed rate were justified (see Table 9). On September 2, 1977, the feed rate was lowered to 2500 lbs/24 hrs. This feed rate resulted in a lower measurement of free and total residual chlorine at the outlet of each condenser (see Table 10). This feed rate was maintained through September. As the inlet water temperatures decreased, the free and total residual chlorine measurements increased with no apparent deterioration in condenser performance as measured by the ACF.

In late September, the feed rate on all units was lowered to a feed rate of 1500 lbs/24 hrs. Measurements at the outlet of the condenser indicated that the chlorinated water effluent was within the effluent limitation guideline requirements ($\leq$0.2 mg/l average free residual chlorine) set by EPA (see Table 11).

As mentioned earlier, the ACF for 1977 was higher on all condensers than the ACF of 1976 except for Unit 4 (see Figure 7). However, the ACFs measured at equal lengths of time after cleaning showed a slight increase in ACF for 1977 compared to 1976. Discussions with Power Production experts in condenser performance and operations indicated that this difference is primarily due to a decrease in the air leakage for 1977 compared to 1976. Considering this data and a visual condenser inspection of Unit 4, we conclude that there has been no apparent decrease in condenser performance that could be attributed to lower feed rates of chlorine.

TABLE 9. SAMPLES TAKEN AT OUTLET ON AUGUST 25, 1977

Unit	Feed Rate (lb/24 hrs)	FRC* Outlet (mg/l)
1	2500	.08
2	3000	.25
3	3000	.25
4	unit off line	

TABLE 10. SAMPLES TAKEN AT OUTLET ON SEPTEMBER 2, 1977

1	2500	.23
2	2500	.16
3	2500	.22
4	2500	.14

TABLE 11. SAMPLES TAKEN AT OUTLET ON SEPTEMBER 30, 1977

1	1500	.18
2	1500	.04
3	unit off line	
4	1500	.05

*Average of steady-state outlet-free residuals.

PHASE III - OCTOBER 1977 THROUGH DECEMBER 1978

The Approach

The objective of Phase III was to determine the optimum chlorination regime at the plant. Low levels of chlorine residuals were to be maintained at the outlet of the condenser as long as no apparent loss in condenser performance was noted. Also, one unit was to be tested at a zero chlorine feed rate to determine if the plant needed to chlorinate at all.

In addition, all units would be tested at a chlorine feed regime of three doses per day for 20 minutes per dose. Again, condenser performance was to be the controlling factor.

The Program

The chlorine feed rate to all units was 1500 lb/24 hrs from October 1, 1977, through April 13, 1978, due to the low inlet water temperatures (approximately 35°-60°F). The average FRC concentrations ranged between .05-.15 mg/l (most average values ranging between .05 and .10 mg/l) with no apparent loss in ACF. A comparison of the condenser performances for all three phases may be found in Figure 8.

The analysis of Phase II data indicated that the chlorine feed rate generally varied directly with inlet water temperature. Since the ultimate objective of this project was to minimize to the point of zero chlorine feed, a test procedure was developed to determine if a unit at John Sevier could operate efficiently without the use of chlorine when the inlet water temperature was very low.

Unit 1 condenser was tested for six weeks at a zero chlorine feed rate prior to the unit's scheduled outage. The inlet water temperature during this time was 35°F. For five weeks (January 3-February 10), the condenser performance was generally the same as the other two units on line which were being chlorinated. Within three days (February 10-13), the condenser performance dropped from 85 percent down to 74 percent, as can be seen in Figure 9. Chlorination of Unit 1 was resumed on February 13 until its scheduled outage.

To ensure that the results obtained on Unit 1 were not unique to that unit, the plant recommended that Unit 3 should also be tested at a zero chlorine feed rate. The inlet water temperature during the test period ranged from 38°-45°F. Unit 3 gave approximately the same results as Unit 1 (see Figure 9). For five weeks, the ACF was comparable to the other units. Then, within three days, the ACF dropped from 83 percent to 69 percent. Chlorination was returned to this unit.

A visual inspection of both condensers indicated that excessive biofouling had occurred. Manual cleaning was required to return the units to acceptable operating efficiencies. The condenser inspections made during these studies may be found in Appendix I.

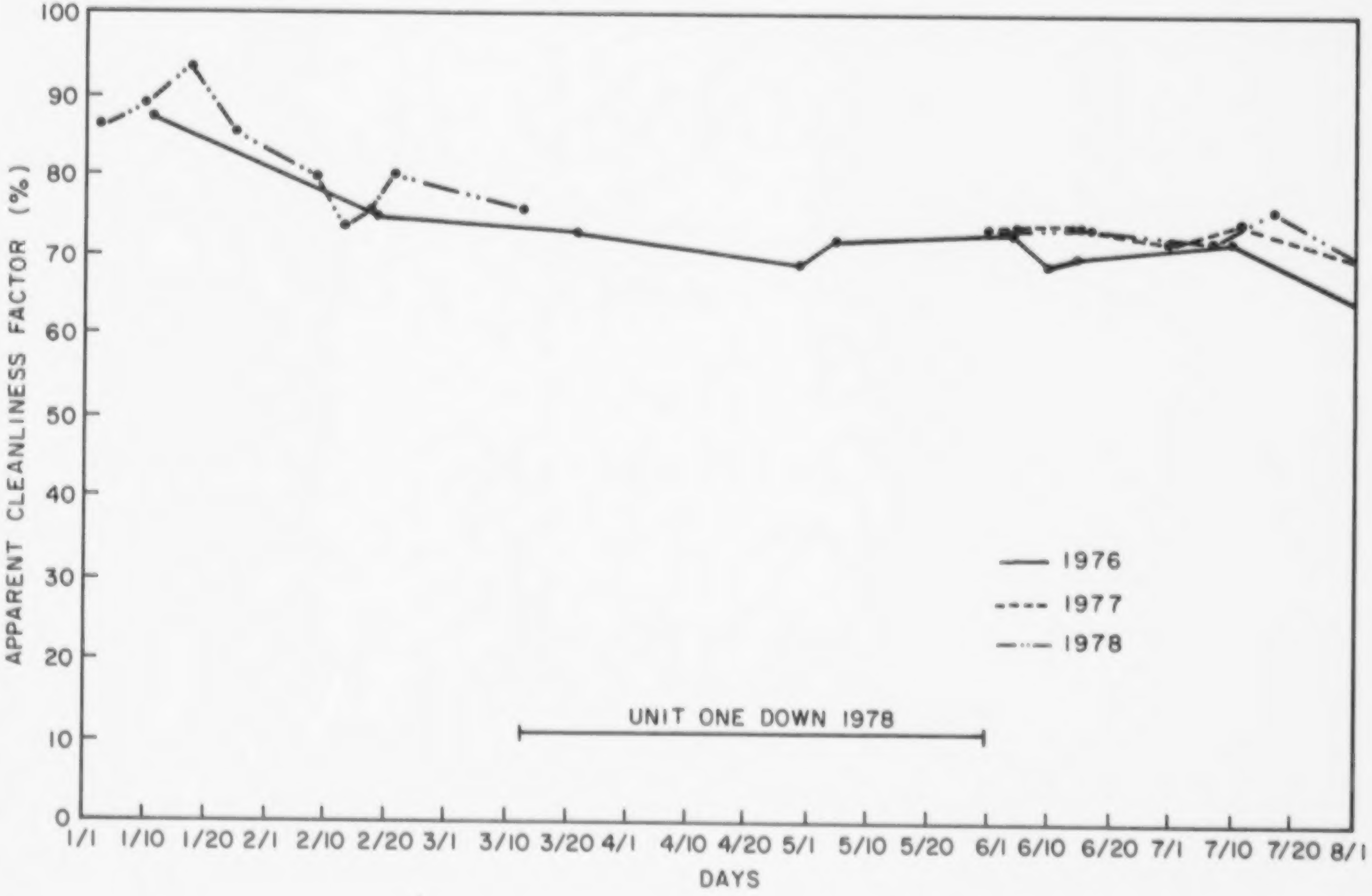


Figure 8. Unit 1 1976 vs. 1977 vs. 1978 apparent cleanliness factor.

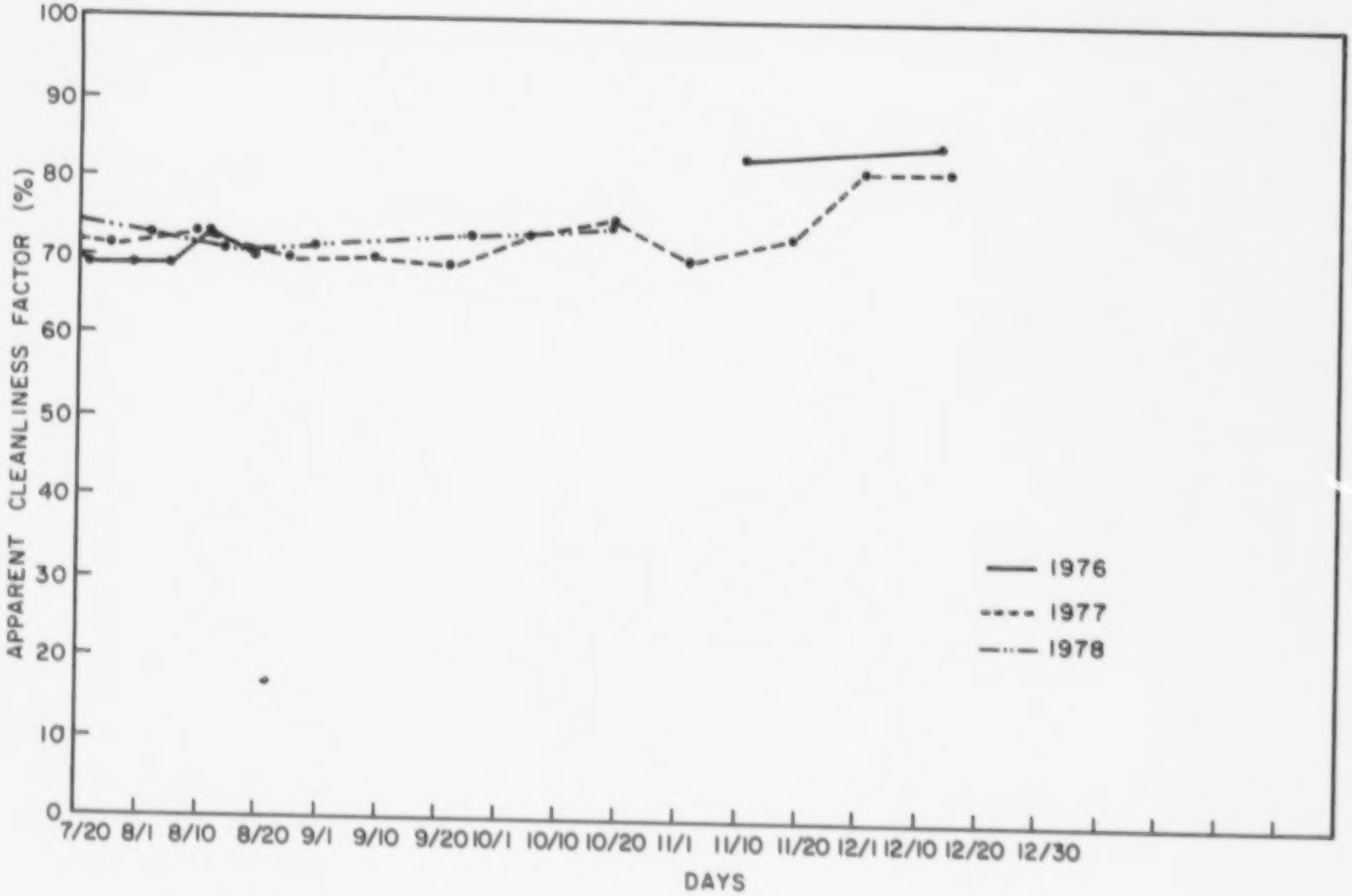


Figure 8 (continued). Unit 1 1976 vs. 1977 vs. 1978 apparent cleanliness factor.

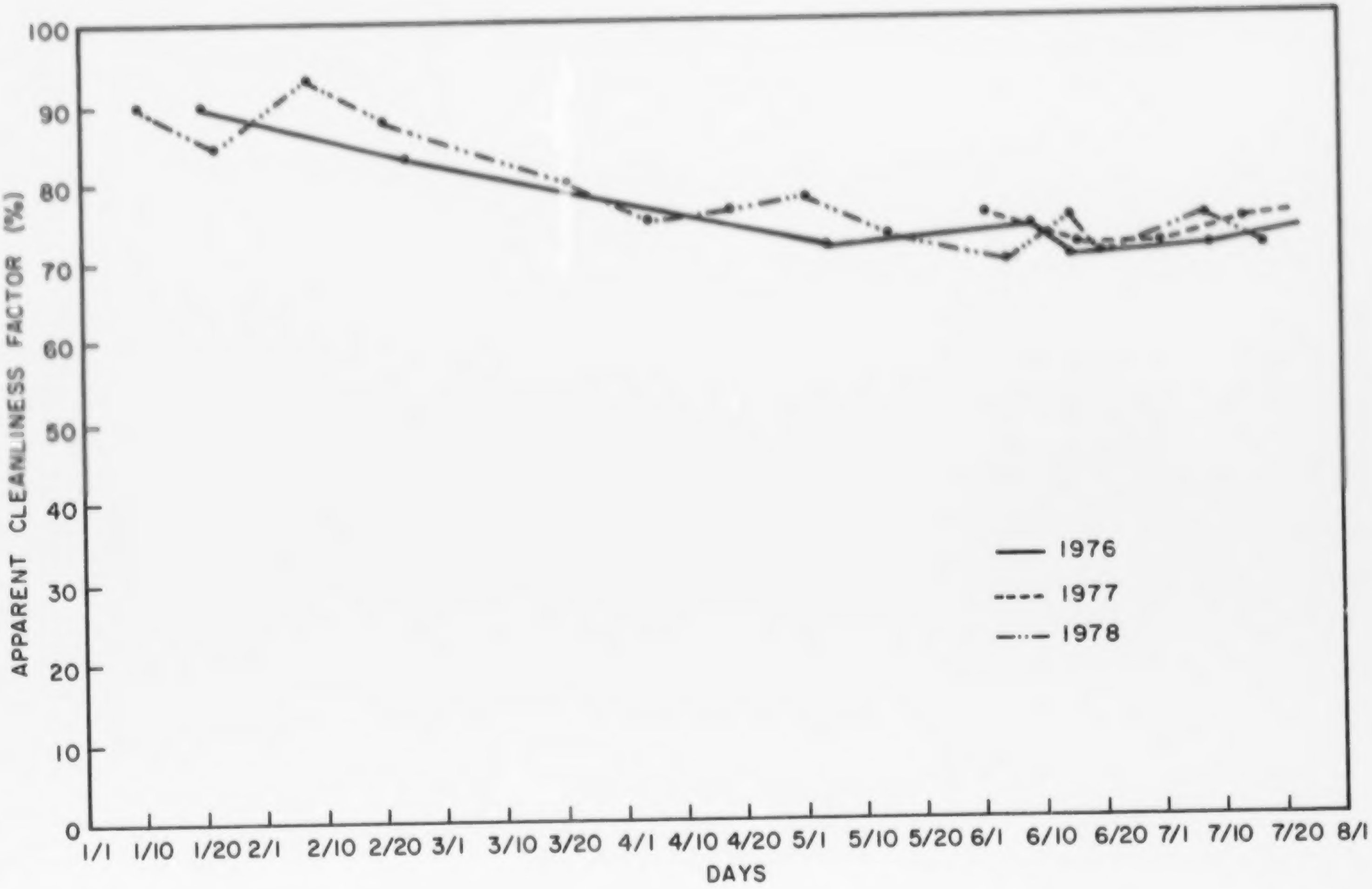


Figure 8 (continued). Unit 2 1976 vs. 1977 vs. 1978 apparent cleanliness factor.

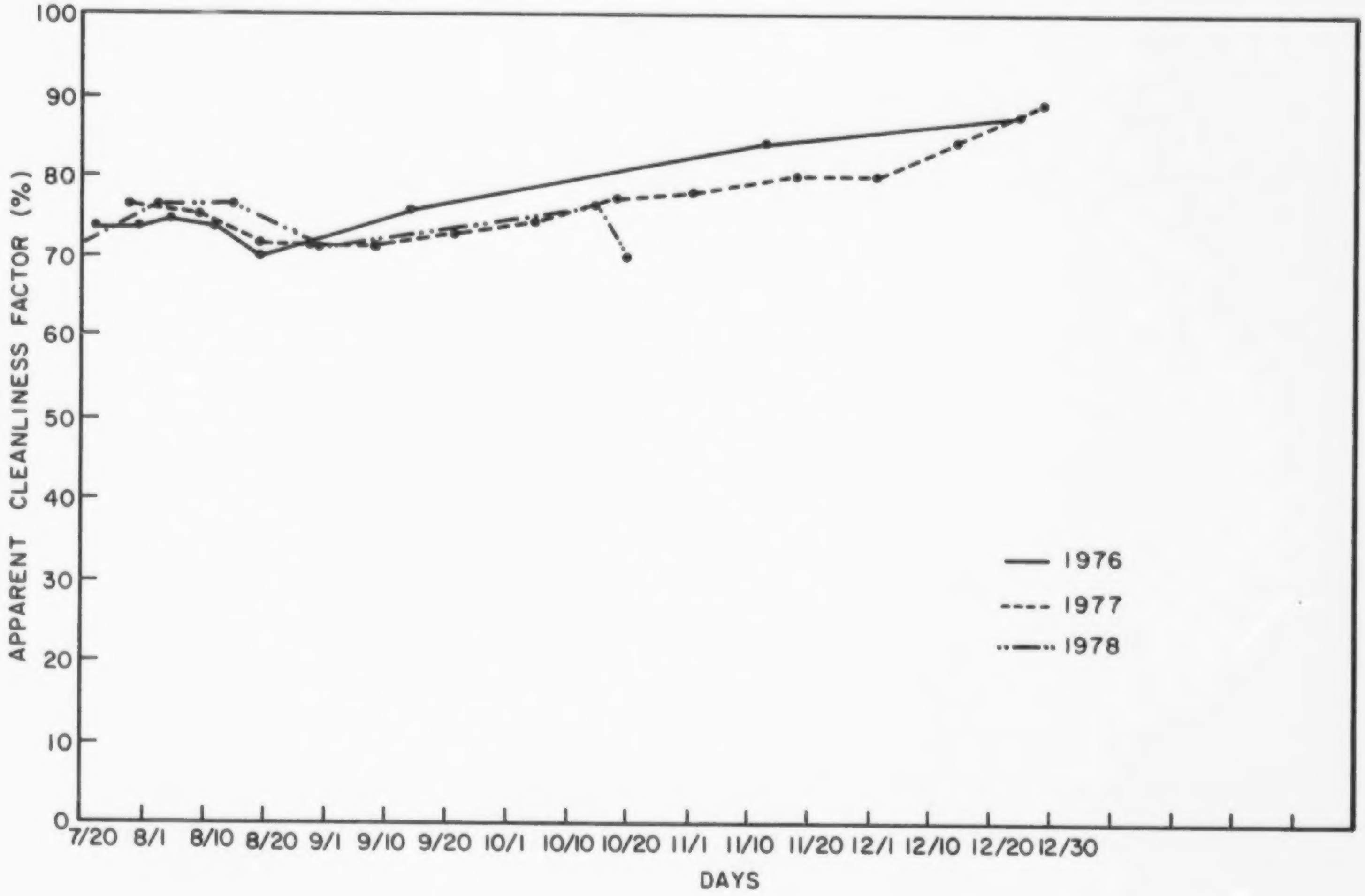


Figure 8 (continued). Unit 2 1976 vs. 1977 vs. 1978 apparent cleanliness factor.

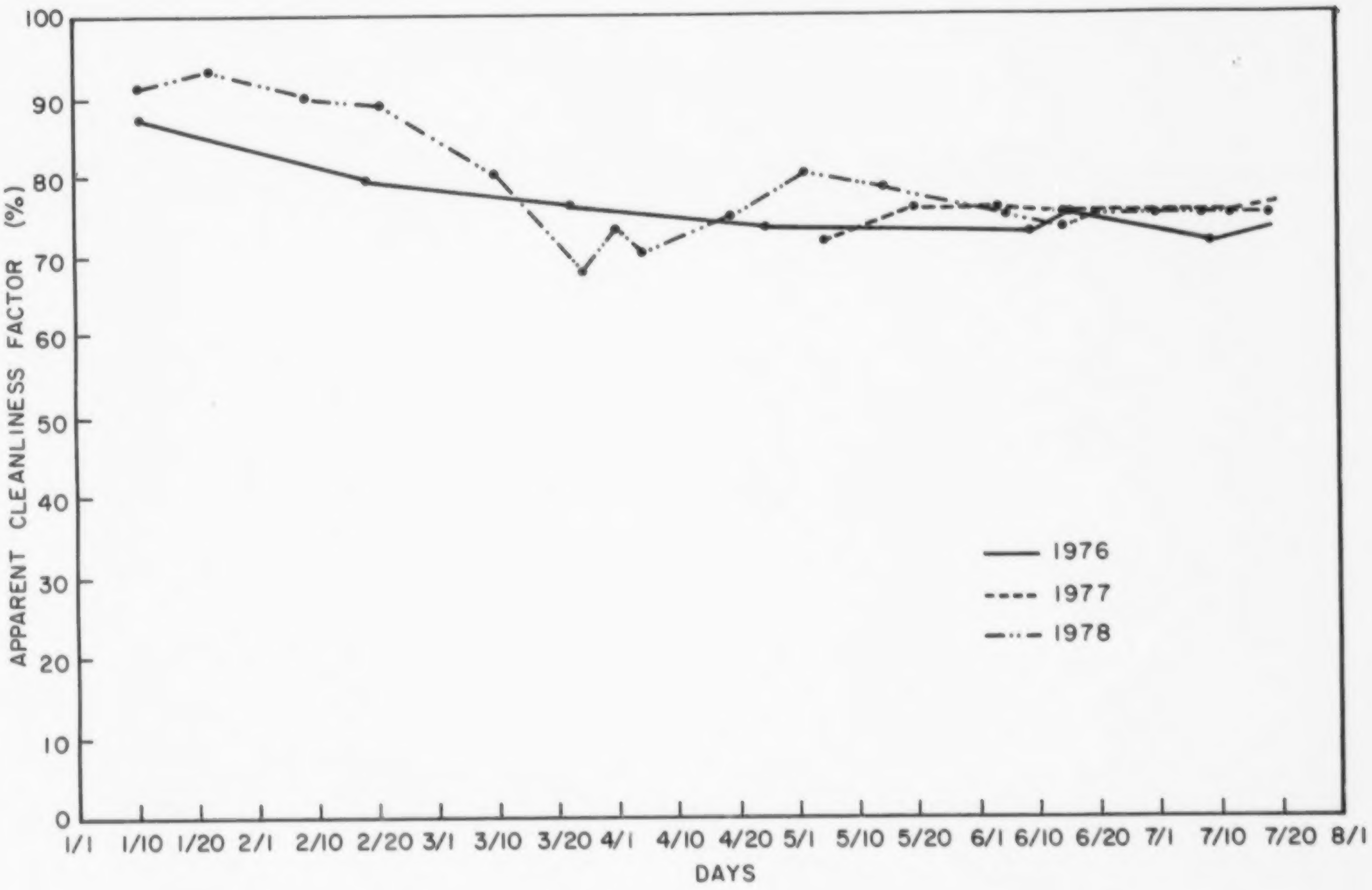


Figure 8 (continued). Unit 3 1976 vs. 1977 vs. 1978 apparent cleanliness factor

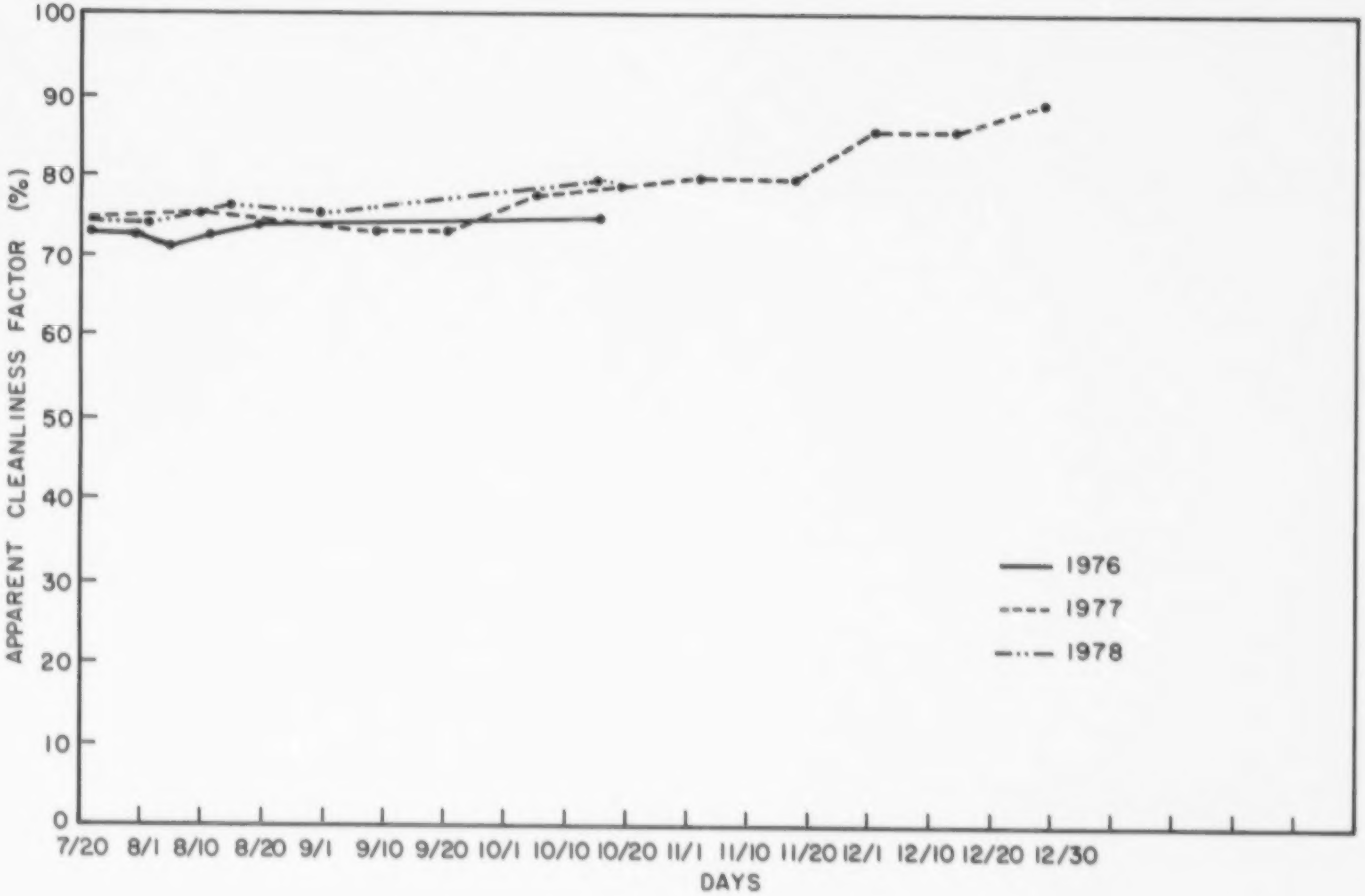


Figure 8 (continued). Unit 3 1976 vs. 1977 vs. 1978 apparent cleanliness factor

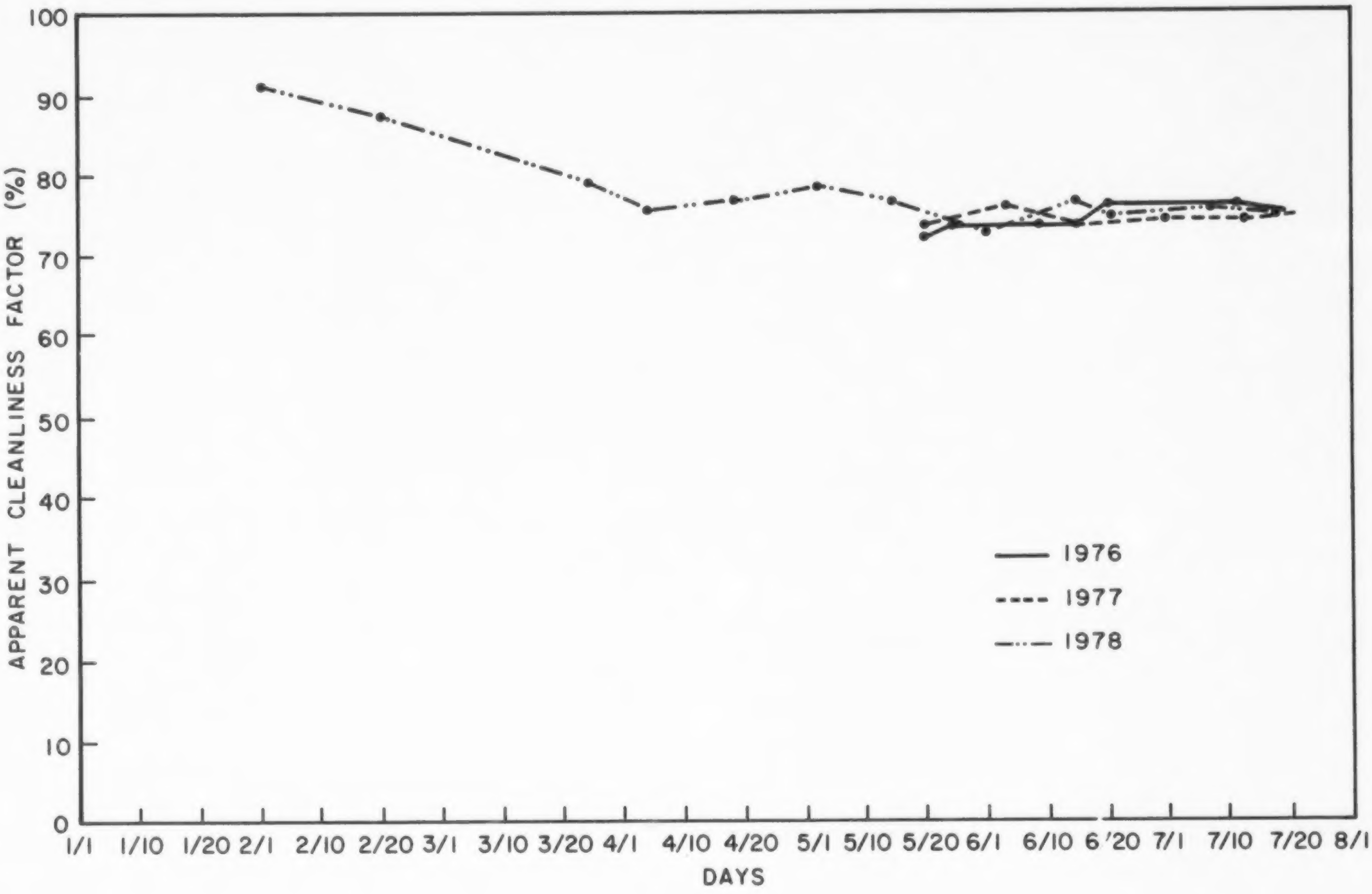


Figure 8 (continued). Unit 4 1976 vs. 1977 vs. 1978 apparent cleanliness factor

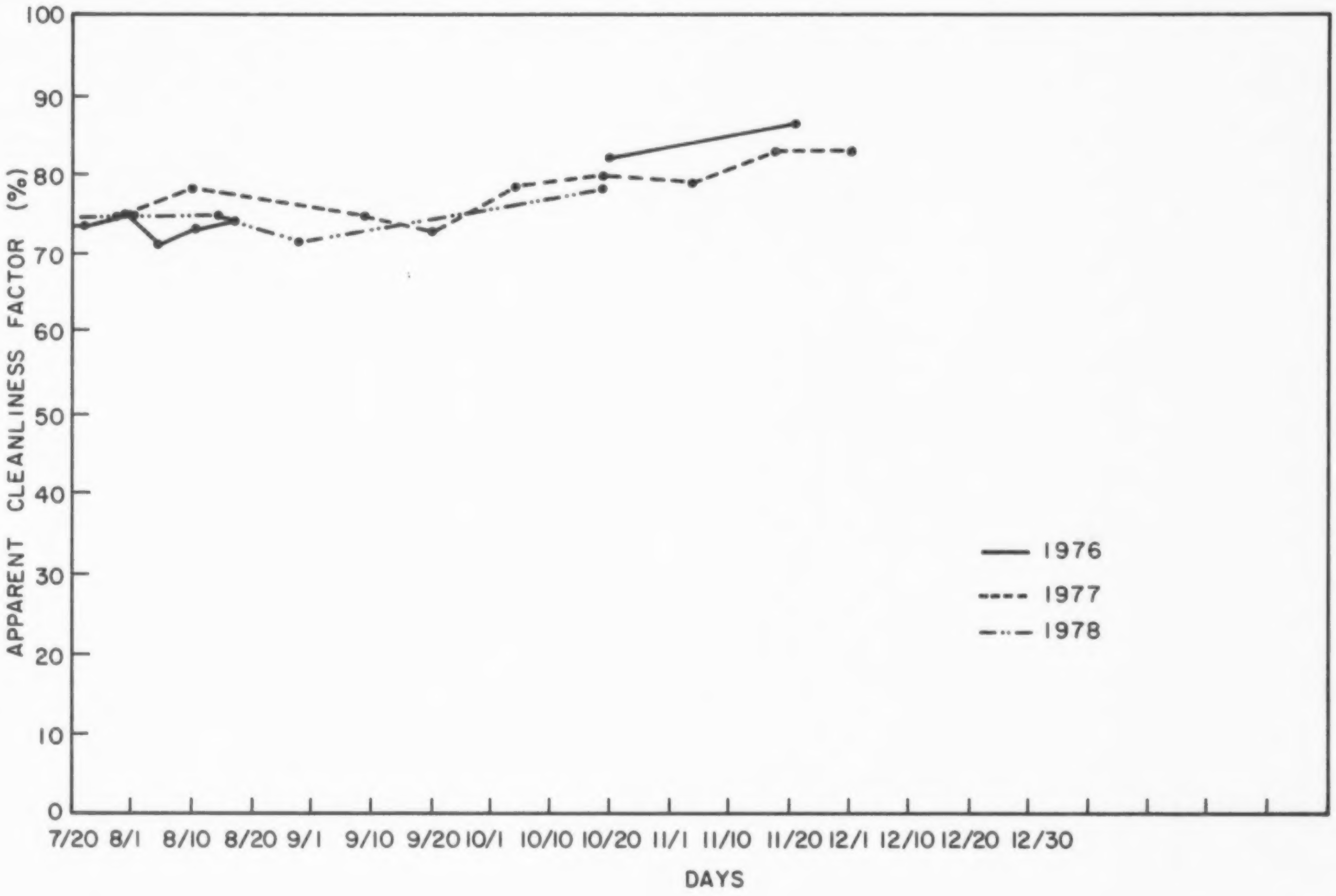


Figure 8 (continued). Unit 4 1976 vs. 1977 vs. 1978 apparent cleanliness factor

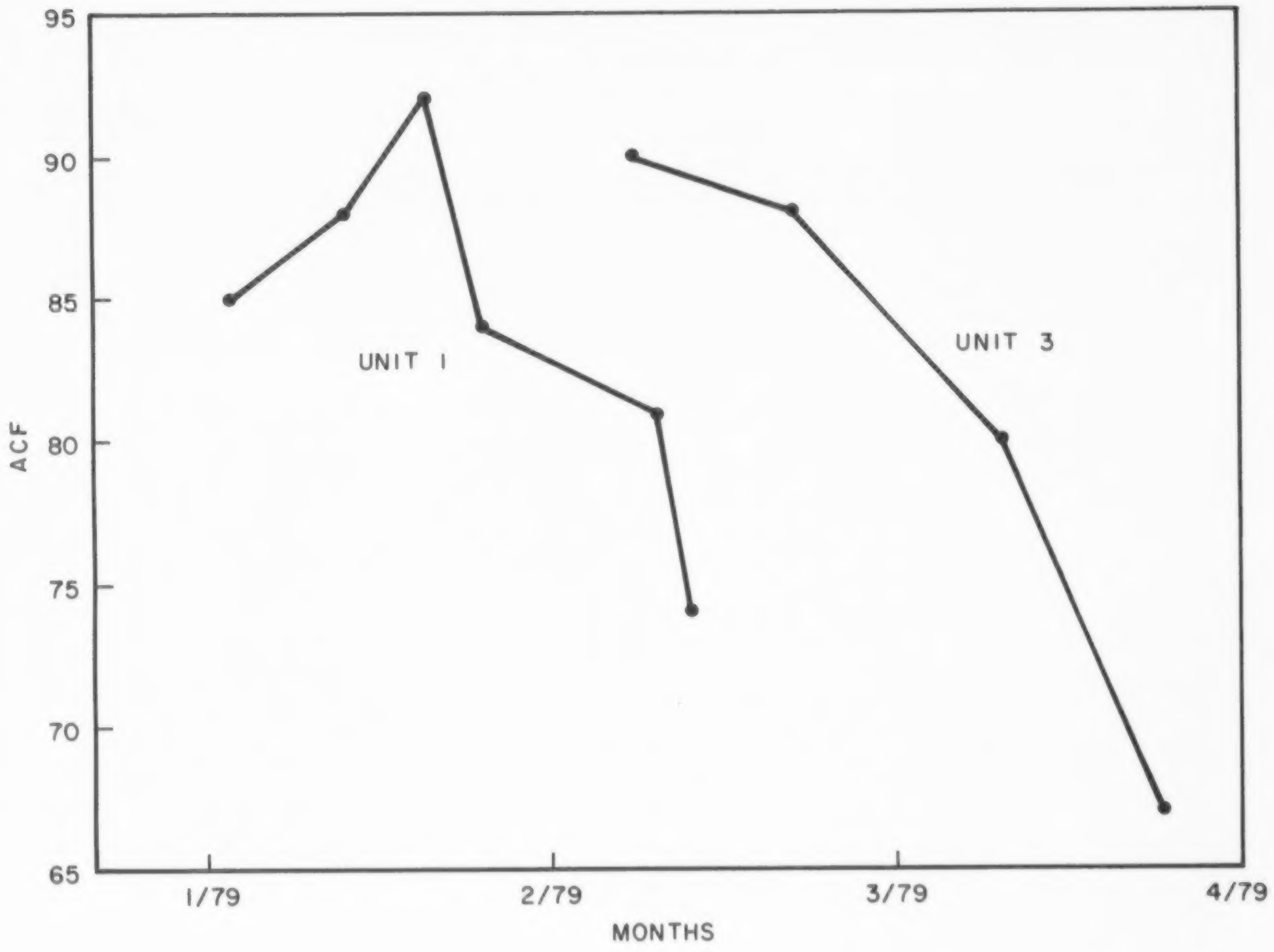


Figure 9. Condenser performance - units I and 3

On April 13, 1978, the chlorine feed rate was increased from 1500 to 2000 lb/24 hrs on Unit 3 due to increasing inlet water temperatures (from 38°F in February to 65°F in April) and very low outlet FRC concentrations (approximately .05 mg/l). The results of this test and previous tests indicated that the feed rate should be increased for all units. Therefore, on April 14, 1978, the chlorine feed rate was increased to 2000 lb/24 hrs. On April 28 and May 4, 1978, the chlorine feed rate was increased from 2000 lb/24 hrs to 2500 lb/24 hrs and 3000 lb/24 hrs, respectively, for the same reasons as above.

During the months of May and June, it was noted that the chlorine demand of the water, the chlorine consumption through the system, and the inlet water temperature exhibited large variations. These variations had a profound effect upon the chlorine feed rate as can be seen in Figures 10 and 11. The feed rate necessary to maintain a .10-.20 mg/l FRC concentration at the condenser outlet varied from 2500 lb/24 hrs to 3500 lb/24 hrs. It is obvious that chlorine monitoring should be done quite often during this period for two reasons: (1) to ensure that sufficient levels of chlorine are available to combat biofouling; and (2) to ensure compliance with NPDES permits.

At the end of June, the chlorine demand of the cooling water stabilized, and it was noted that although the inlet water temperature was rather high (78°F), 3000 lb/24 hrs feed rate was more than necessary to control potential biofouling. Therefore, the feed rate was reduced to 2500 lb/24 hrs on July 18, 1978. This feed rate was continued for the remainder of the study. At 2500 lb/24 hrs feed rate, the average FRC concentrations at the outlet of the condensers were .12 mg/l during July.

On May 31, July 18, and August 29, 1978, representatives from the TVA Water Quality and Ecology Branch conducted measurements for FRC and TRC in the discharge canal just below the effluent from Unit 4 and in the Holston River at the mouth of the discharge canal. Their results may be found in Tables 12-14. It can be seen from the data that no FRC was found in Tables 12-14. It can be seen from the data that no FRC was found in the river or the discharge canal. It should be noted that the FRC residuals at the condenser outlet were much higher than normal at this particular period of time (0.42 mg/l FRC).

The results of Phase III indicated that by maintaining a free residual chlorine concentration of 0.1 to 0.2 mg/l at the outlet of a condenser, condenser performance will not be inhibited and permit limitations will be met.

The data from Phase II indicated that frequency and duration of chlorine feed have an effect on condenser performance. It was noted that chlorine feed of six times per day for 10 minutes and three times per day for 20 minutes rendered better condenser performance (optimization of chlorination) than feeding chlorine for two times per day for 30 minutes or two times per day for one hour. In July 1978, the chlorine feed regime was changed to three times per day for 20 minutes on all units. No loss in condenser performance was noted after this change.

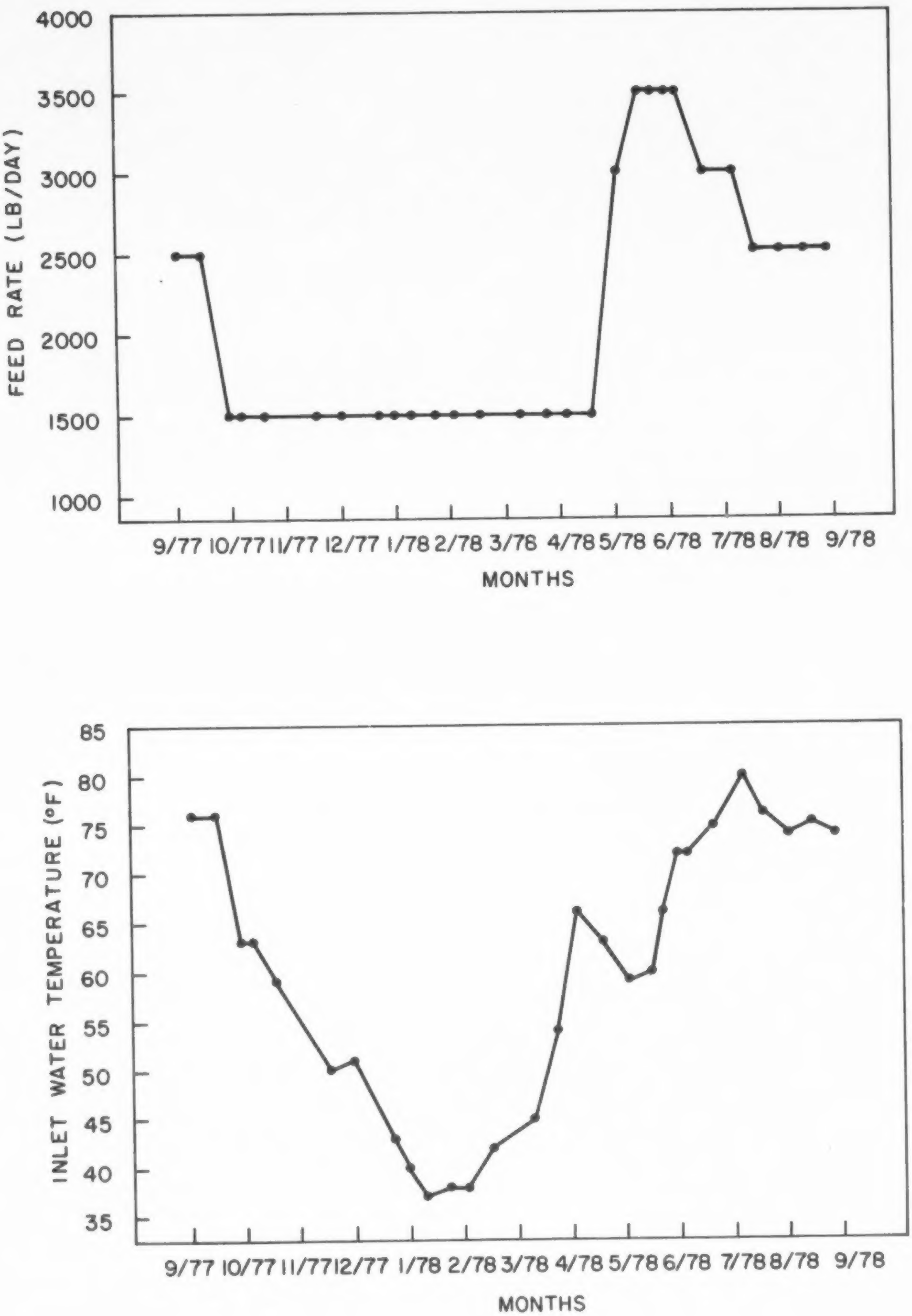
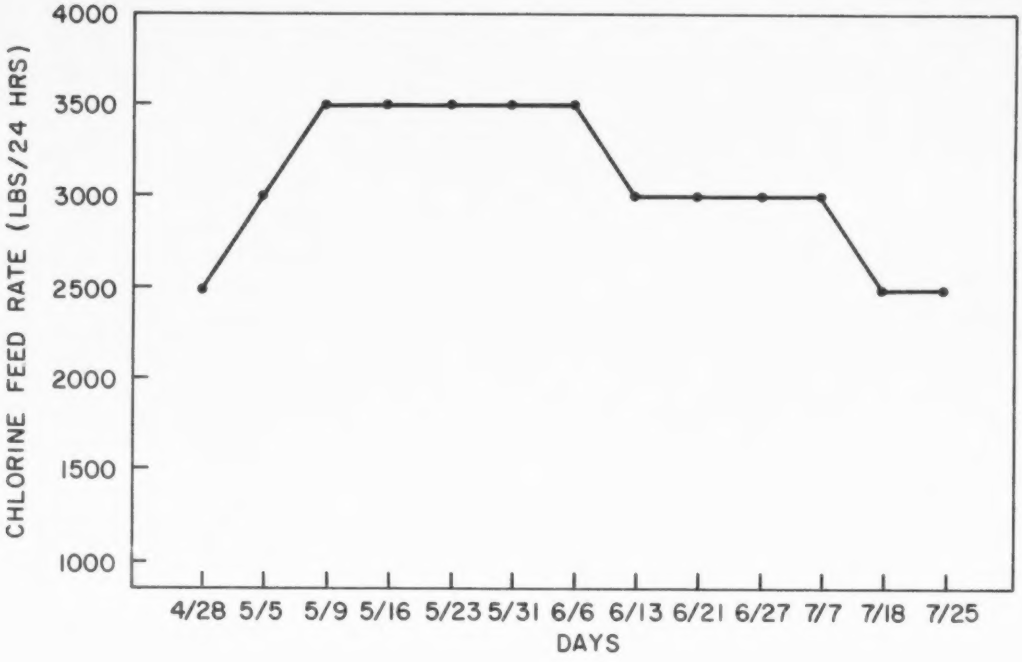


Figure 10. Feed rate vs. inlet water temperature



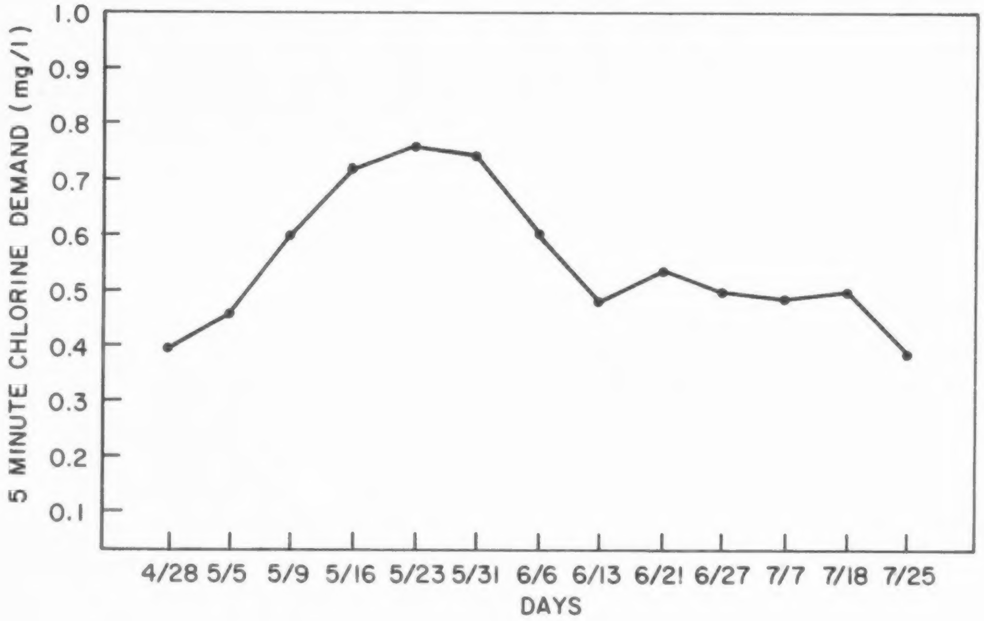


Figure 11. Feed rate vs. chlorine demand

Table 12

MEASUREMENTS IN RIVER
MAY 31, 1978
INSTRUMENT #1

From Left Bank				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	mg/1 Total
5%	8:30 am	26.5°C	Background	0	0
	Tap Water Check			0	1.10*
Polly Branch	9:55 am		11	0	0
Polly Branch	9:55 am		385	0	0
Polly Branch	9:55 am		5	0	0
Holston RM 105.3			375	0	0
Above Polly Branch			13	0	0
Above Polly Branch			13	.05	.05
5%	11:00 am	27.0		0	0
	11:15 am	27.0		0	0
	11:30 am	27.0		0	0
	Tap Water Check			0	0.66*
	11:40 am	27.0		0	0
	11:50 am	27.0		0	0
	12:00 pm	27.0		0	0
	12:15 pm	27.0		0	0.02
	12:30 pm	27.0		0	0.05
	12:35 pm	27.0		0	0.05
	12:40 pm	27.0		0	0.06
	12:45 pm	27.0		0	0.05
	12:50 pm	27.0		0	0.05
	12:55 pm	27.0		0	0.05
	1:00 pm	27.0		0	0.05
	1:10 pm	27.0		0	0.04
	1:20 pm	27.0		0	0.05
	1:30 pm	27.0		0	0.05
	Tap Water Check			0	0.04*
	1:40 pm	27.0		0	0.02
	1:50 pm	27.0		0	0.02

*Tap Water

Table 12 (Continued)

MEASUREMENTS IN RIVER*
MAY 31, 1978
INSTRUMENT #2

				Chlorine mg/l	
	Time	Temp		Free	Total
	10:55 am	27.0°C		0	0
	11:03 am	27.0		0	0
	11:10 am	27.0		0	0
	11:20 am	27.0		0	0
	11:25 am	27.0		0	0
	11:30 am	27.0		0	0
	11:40 am	27.0		0	0
	11:50 am	27.0		0	0
	12:00 noon	27.3		0	0
	12:05 pm	27.5		0	0
	12:10 pm	27.6		0	0.20
	12:14 pm	27.7		0	0.10
	12:18 pm	27.8		0	0
	12:22 pm	27.8		0	0
	12:25 pm	28.0		0	0
	12:31 pm	27.8		0	0
	12:35 pm	27.7		0	0.78
	12:40 pm	27.8		0	0.62
	12:43 pm	27.8		0	0.68
	12:47 pm	27.8		0	0.62
	12:51 pm	27.8		0	0.69
	12:54 pm	27.8		0	0
	12:57 pm	27.8		0	0
	1:01 pm	27.8		0	0
Extra	1:06	28.5	100 yds. below channel	0	0
Extra	1:10	28.5	4 yds. below channel	0	0

*Air boat anchored in discharge channel just below effluent from Unit 4. Chlorine injection being done manually. Schedule: Unit 1 - 11:00 to 11:20 a.m. Unit 2 - 11:30 to 11:50 a.m. Unit 3 (chlorinated but unit not operating) - 12:00 to 12:20 p.m. Unit 4 - 12:30 to 12:50 p.m.

Table 13

MEASUREMENTS IN DISCHARGE CANAL
JULY 18, 1978

% From Left Bank of Discharge Canal				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	Total
Blank	(added CL_2 to blank)			2.1	2.38
17	8:30 am			0	0
33				0	0
50				0	0
67				0	0
84	8:34			0	0
	Chlorinating Unit 2 from 9:00 a.m. to 9:30 a.m.				
17	9:05	88	6	0	0
33		88	18	0	0
50		87	62	0	0
67		87	269	0	0
84	9:11	85	356	0	0
17	9:15	88	391	0	.35
33		86	236	0	.42
50		87	11	0	.02
67		88	3	0	0
84	9:19	88	2	0	0
17	9:24	80	15	0	.24
33		87	18	0	.43
50		88	22	0	0
67		87	23	0	0
84	9:28	87	43	0	0
17	9:37	87	13	0	.38
33		88	271	0	.47
50		88	128	0	.03
67		88	14	0	0
84	9:41	89	11	0	0
17	9:51	89	18	0	0
33		88	43	0	0
50		88	23	0	0
67		88	22	0	0
84	9:55	89	15	0	0

Table 13 (Continued)

MEASUREMENTS IN DISCHARGE CANAL
JULY 18, 1978

% From Left Bank of Discharge Canal				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	Total
Blank				.30	.40
Chlorinating Unit #4 from 10:00 a.m. to 10:10 a.m.					
17	10:10 am	88	22	0	0
33		88	11	0	0
50		87	128	0	0
67		89	15	.25*	.37
84	10:14	87	23	.03	.22
17	10:20	88	13	0	0
33		88	43	0	0
50		88	18	0	0
67		88	14	0	0
84	10:24	89	271	0	0
Chlorinating Unit #3 from 11:00 a.m. to 11:20 a.m.					
17	11:10	89	18	0	0
33		88	43	0	.02
50		88	271	0	.38
67		90	13	0	.08
84	11:14	89	14	0	.08
17	11:20	89	23	0	0
33		89	15	0	.02
50		89	11	0	.33
67		89	128	0	.07
84	11:24	89	22	0	.07
17	11:30	89	391	0	0
33		89	236	0	0
50		89	11	0	.05
67		89	2	0	0
84	11:34	89	3	0	0

*Doubtful value since the maximum FRC concentration measured at the condenser outlet was 0.14 mg/l.

Table 13 (Continued)

MEASUREMENTS IN DISCHARGE CANAL
JULY 18, 1978

% From Left Bank of Discharge Canal				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	Total
Chlorinating Unit #1 from 12:00 to 1:00 p.m.					
17	12:10 pm	90	15	0	.35
33		89	11	0	.02
50		89	43	0	0
67		89	14	0	0
84	12:14	89	13	0	0
10	12:25	90	356	0	.52
33		89	269	0	.05
50		89	62	0	0
67		89	18	0	0
84	12:29	89	6	0	0
10	12:40	90	11	.30*	.47
25		90	15	0	.08
50		89	14	0	0
67		90	13	0	0
84	12:44	90	43	0	0
10%	12:48	90	Sample taken ± 50' below the mouth of discharge canal in Holston River	0	.21

All of the samples above were collected ± 150' up in discharge canal. Moved sampling location to ± 40' in discharge canal (below rapids).

% Loc.	Time	Temp	Bottle No.	Free	Total
10%	12:55	89	271	0	.02
50	12:56	89	18	0	0
75	12:57	90	23	0	0
10	13:10	90	15	0	0
50	13:11	89	356	0	0
75	13:12	90	23	0	0

*Doubtful value since the maximum FRC concentration measured at the condenser outlet was 0.16 mg/l.

Table 14

MEASUREMENTS IN DISCHARGE CANAL
AUGUST 29, 1978

From Left Bank of Canal				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	Total
Background Cl_2 Water				4.0	4.4
10	8:25	25.5		0	0
60	8:30	25.5		0	0
90	8:35	26.0		0	0
	Unit #1 9:00 to 9:20 a.m.				
10	8:57	26.0		0	0
60	9:00	26.3		0	0
90	9:03	26.3		0	0
10	9:10	26.2		0	0
60	9:13	27.0		0	0
90	9:16	26.5		0	0
10	9:20	27.0		0	0
60	9:23	27.0		0	0
90	9:26	26.2		0	0
10	9:30	20.3		0	0
60	9:33	27.0		0	0
90	9:35	26.3		0	0
10	9:40	27.0		0	0
60	9:43	27.1		0	0
90	9:45	27.0		0	0
	Cl_2 Water (Test) (Unit 2)			2.85	2.95
10	10:03	27.0		0	0
60	10:05	27.0		0	0
90	10:07	27.0		0	0
10	10:11	27.0		0	0
60	10:13	27.1		0	0.05
90	10:15	27.0		0	0
10	10:20	27.0		0	0
60	10:22	27.0		0	0.11
90	10:25	27.0		0	0.02
10	10:30	27.0		0	0.13
60	10:33	27.1		0	0
90	10:36	27.1		0	0

Table 14 (Continued)

MEASUREMENTS IN DISCHARGE CANAL
AUGUST 29, 1978

From Left Bank of Canal				Chlorine	
% Loc.	Time	Temp	Bottle No.	Free	Total
10	10:40	27.0		0	0
60	10:42	27.0		0	0
90	10:45	27.0		0	0
Unit #3 11:00 to 11:20 a.m.					
10	11:03	27.0		0	0
60	11:05	27.0		0	0
90	11:07	27.0		0	0
10	11:10	27.0		0	0
60	11:12	27.0		0	0
90	11:14	27.0		0	0
10	11:20	27.0		0	0
60	11:22	27.2		0	.24
90	11:24	27.0		0	.10
10	11:31	27.3		0	0
60	11:35	27.3		0	.24
90	11:37	27.2		0	.08
10	11:41	27.3		0	0
60	11:44	27.6		0	0
90	11:46	28.0		0	0
Unit #4 12:00 to 12:20 p.m.					
10	12:10	27.5		0	0
60	12:13	27.7		0	0
90	12:15	28.0		0	0
10	12:18	28.0		0	0
60	12:20	28.0		0	0
90	12:22	28.0		0	.25
10	12:27	28.0		0	0
60	12:29	28.0		0	0
90	12:31	28.5		0	.29
10	12:36	27.5		0	0
60	12:38	28.0		0	0
90	12:40	28.0		0	0
90	12:43	28.2		0	0

Total Cl_2 = .01 to .02 from discharge canal to within 4+ mile above boat ramp.

In addition to sustained condenser efficiency, this feed rate is desirable for the following reasons:

1. The condenser is chlorinated once per shift.
2. The length of feed allows sufficient time for periodic grab sample analysis.

SECTION 7

STATISTICAL ANALYSIS SUMMARY

Introduction

This section summarizes the major findings of the three-phase study of chlorine minimization conducted at the John Sevier Steam Plant and focuses on integrating the results from all three phases into a comprehensive overview. Special emphasis is placed on condenser performance, residual chlorine at the condenser outlet, the relationship of water quality parameters to chlorine minimization, and potential lower limits to the chlorination scheme at John Sevier. General recommendations for chlorine minimization studies are also made.

Phase I of the study was a pilot phase intended to gather information to design the Phase II of the study. Phase I focused on determining the proper "direction" for frequency and duration of feed as well as collecting descriptive data on the chlorination procedure in use at that time with its associated parameters.

Based on the Phase I results, a more detailed test program with lower feed rates and different combinations of frequency and duration of feed were investigated in Phase II. The results from Phase II allowed the development of a chlorination procedure which was implemented and conducted in Phase III. In general, Phase III substantiated the hypotheses proposed from Phase II, and indicated that lower limits of chlorination may be possible. We say "may" because Phase III indicated the strong possibility of byproducts "masking" the true levels of FRC and TRC in the system. Caution must therefore be used.

Apparent Cleanliness Factor

This section focuses on two major questions: (1) Has the condenser performance, as measured by ACF, been adversely affected by the chlorine minimization program?; and (2) Based on all available data, what are the major factors influencing ACF?

Condenser Performance: 1974-1978--

The major motivation for the entire chlorination study was to determine if adequate condenser performance could be maintained at lower chlorine feed rates. The following analysis compares ACF readings over time to determine if condenser performance has been significantly affected since the chlorine minimization program was started. Table 15 gives the annual ACF by unit with the sample size in parentheses and the overall annual ACF.

TABLE 15. ACF'S FOR THE PERIOD 1974-1978

Year	Unit 1	Unit 2	Unit 3	Unit 4	Overall ACF
1974	74.87 (3)	76.06 (5)	78.97 (5)	76.35 (3)	76.80 (16)
1975	73.86 (8)	74.70 (5)	77.38 (8)	76.70 (9)	75.79 (30)
1976	73.37 (15)	75.88 (14)	74.39 (13)	75.88 (14)	74.86 (56)
1977	73.56 (16)	75.63 (16)	77.44 (16)	76.21 (14)	75.69 (62)
1978	76.83 (18)	76.50 (18)	77.67 (21)	76.75 (16)	76.97 (73)

At first glance, the overall ACF seemed to decline from 1974 through 1976 and then started rising again. Since the chlorine minimization program was started in May of 1976, the decline from 1974 to 1975 cannot be attributed to the lower feed rate. No inlet water temperatures were available for these years, so it cannot be conclusively labeled as inlet water temperature variation. Since the chlorine minimization program started, feed rates have been lowered substantially; so if there was a significant deterioration of condenser performance as measured by ACF, it would seem that the ACF would have steadily declined.

To test if the chlorine minimization program has had an adverse effect on condenser performance, the available ACF data were divided into two groups--the first being all ACF data prior to the minimization program, and the second, ACF data gathered since. The difficulty in assessing the difference between the two group means is the estimation of an appropriate standard error to determine if the difference is significant or not. A comparison of the variation in each group was made, but they were not significantly different and were combined into a single estimate. The result of the statistical test indicated no significant difference in the average ACF before or during the chlorine minimization study. This conclusion is based on several simplifying assumptions which had to be made since no data were available to estimate and remove the effects of inlet water temperature, etc. The following table summarized the statistical test:

TABLE 16. TEST OF CONDENSER PERFORMANCE - BEFORE AND DURING STUDIES

Before	During	F Test for Equality of Variances
$m = 57$	$m = 180$	$F_{calc} = 5.4464^2/4.8764^2 = 1.247$
$\bar{X} = 76.30$	$\bar{X} = 75.69$	Not significantly different at
$s = 5.4464$	$s = 4.8764$	$\alpha = .05$

Test of Difference in Mean ACF's

Pooled $S^2 = 25.1816$ $\therefore$ standard error = 0.7627

$$Z_{calc} = \frac{76.30 - 75.69}{0.7627} = \frac{0.61}{0.7627} = 0.7998$$

Not significantly different at $\alpha = .05$.

Conclusion: There has been no detectable deterioration in condenser performance during the chlorine minimization study.

Major Factors Influencing Condenser Performance as Measured by ACF:

The major factor influencing ACF for a fixed feed, frequency, and duration of chlorination was water temperature. The effects of water temperature are extremely large when compared to other factors. These effects are large because increases in water temperature promote, among other things, biofouling while also increasing the chlorine demand of the water which results in less chlorine available as a mechanism for biofouling control. A 3°F rise in temperature on the average results in a 1 percent ACF reduction.

The second most important factor influencing ACF was the amount of free residual chlorine available at the condenser inlet. The FRC at the condenser inlet in turn was a function of the chlorine dosage, the inlet water temperature, the duration of feed, and various water quality parameters. A regression model characterizing the free residual chlorine to be found at the condenser inlet has been developed. Since it is based on Phase II and III data combined, a note of caution must be made--Phase II data were collected with a faulty chlorinator while Phase III, for the majority of the data, had a new chlorinator. Therefore, simply combining the data, fitting a regression model and expecting accurate, unbiased results cannot be done. The regression model was developed as a point of reference and as an aid for discussion and further investigation. Having qualified the model, it is

$$\text{FREE-IN} = 0.7213 - 0.0011\ \text{COND} - 1.0946\ \text{ORGN} + 0.4118\ \text{CL}_2 - 0.0073\ \text{IWT}$$

where FREE-IN is the amount of free residual chlorine (mg/ℓ) available at the condenser inlet, COND is conductivity (μMHOS), ORGN is organic nitrogen (mg/ℓ), CL_2 is the chlorine dosage (mg/l), and IWT is the inlet water temperature (°F). This model had an r^2 of 0.66, EMS of 0.0166, and an F value of 21.41, based on 4 parameters and 45 degrees of freedom.

This model indicates that a rise in conductivity or organic nitrogen or inlet water temperature reduces the amount of FRC at the condenser inlet. Also, as the chlorine dosage increases, the FRC at the condenser inlet increases.

Another important factor affecting ACF was the frequency of feed. Phase II data indicated that lower feed rates combined with more frequent dosing of the system maintained condenser performance. Frequency of feed must be combined with an appropriate dosage of chlorine to provide sufficient FRC at the condenser inlet to meet condenser demand.

To maintain satisfactory condenser performance while minimizing/optimizing chlorination, an appropriate feed, frequency, and duration scheme must be devised. These factors at John Sevier were found to be highly temperature dependent and a function of the system and condenser demand. The impact of water quality must also be examined for its effects. In studies being conducted at other plants, it is recommended that a similar sequence of tests be done to identify inlet water temperature effects, system and condenser demands, and factors affecting FRC at the condenser inlet, with special attention to the initial chlorine dosage, residuals at the condenser outlet, and water quality parameters.

Residual Chlorine at the Condenser Outlet

Free and total residual chlorine readings at the condenser outlet are a source of two important pieces of information: (1) when combined with condenser inlet readings, condenser demand can be investigated; and (2) the readings can indicate when a chlorination scheme has too high a chlorine dosage. This is not to say that the outlet alone can be used as a control point.

The following table summarizes the total and free residual chlorine at the condenser outlet by phase:

TABLE 17. MEAN FRC AND TRC AT CONDENSER OUTLET FOR PHASES II AND III

Phase	Mean FRC (mg/l)	Mean TRC (mg/l)
II	0.38	1.04
III	0.31	0.86

Table 17 indicates an 18 percent reduction on the average of FRC at the outlet with a 17 percent reduction in TRC between Phases II and III, with no decline in condenser performance. The recommended chlorination scheme, based on Phase II results, was successful in reducing the chlorine level at the condenser outlet.

Several factors seemed to be significantly correlated with the FRC at the condenser outlet. Table 18 lists the factors and the simple correlation coefficient.

The fact that most of the water quality parameters are negatively correlated indicates that as the levels go up, the amount of FRC at the condenser outlet goes down. The positive correlation with the 5- and 10-minute demands is puzzling. As water demand increases, the FRC at the condenser outlet must decrease. Therefore, this correlation analysis is interesting but highly suspect since expected chemical results did not hold true.

TABLE 18. FACTORS CORRELATED* WITH THE FRC AT THE CONDENSER OUTLET

Factor	Simple Correlation Coefficient
Chlorine Dosage	0.62
5-Minute Demand	0.41
10-Minute Demand	0.59
FRC at Condenser Inlet	0.80
Conductivity	-0.26
Alkalinity	-0.42
Total Suspended Solids	0.33
Ammonia	-0.26
Organic Nitrogen	-0.51
Total Nitrates-Nitrites	0.24
Kjeldahl Nitrogen	-0.43

*Significant at the 0.10 level or smaller.

Condenser Consumption of Free Residual Chlorine

Estimated Condenser Demand

Estimates of chlorine consumed in the condenser, called condenser demand for simplicity, have varied substantially during the three phases of the study. Based on system variability, chlorinator malfunctions, and even the variability of condenser demand due to extraneous factors, the average estimates have changed. Phase I estimated condenser demand at 0.5 mg/l FRC with feed rates between 4500 and 6000 lbs/24 hrs. Phase II data estimated condenser demand at 0.08 mg/l FRC with feed rates between 1500 and 4500 lbs/24 hrs. Also noted in Phase II was the decrease in condenser demand of FRC as the feed rate dropped. A feed rate of 4500 lbs/24 hrs had an average condenser demand for FRC of 0.13 mg/l, 2500 lbs/24 hrs had an average demand of 0.07 mg/l, and 1500 lbs/24 hrs had an average of 0.03 mg/l. Phase III estimated condenser demand of FRC at an average of 0.04 mg/l with the bulk of the data from a feed rate of 2500 lbs/24 hrs with its associated average condenser demand of 0.04 mg/l.

In order to meet condenser demand of FRC and ensure adequate disinfecting action, a minimum FRC at the condenser inlet of 0.04-0.08 mg/l must be available. Adding in detection error of about 0.05 mg/l at the chlorine dosages noted in Phase III, a measured FRC of at least 0.09-0.12 mg/l at the condenser inlet appears necessary to ensure that condenser demand is met.

Factors Affecting Condenser Demand

A correlation analysis was carried out to identify factors which may significantly affect condenser demand. Table 19 below summarizes the factors correlated with condenser demand of FRC at a significance level of 0.05 or smaller.

TABLE 19. FACTORS CORRELATED WITH CONDENSER DEMAND OF FRC

Factor	Simple Correlation Coefficient
FRC at Condenser Inlet	0.69
Conductivity	-0.32
Ratio of Condenser Inlet FRC/TRC	0.72

A regression model was estimated which explained 61 percent of the total variation in condenser demand. The model was

$$\text{Delta-F} = -0.2857 + 0.4353\ \text{Free-In} + 0.0039\ \text{ALKA} - 0.1795\ \text{D5}$$

where Delta-F is the predicted condenser demand of FRC, Free-In is the amount of FRC at the condenser inlet, ALKA is the alkalinity of the water, and D5 is the 5-minute chlorine demand of the water. Since this model is based on data combined from Phases II and III, it is intended as a point of reference and discussion and not for prediction. Phase II data were gathered under different circumstances than Phase III, and their combination cannot be depended upon for reliable estimates of the coefficients. However, the factors which are significant and the signs of the coefficients are interesting and seem reasonable. As the FRC at the condenser inlet goes up, condenser demand goes up. As the alkalinity goes up, the demand goes up. As the water demand rises, the condenser demand drops--which seems surprising until you realize that the rise in water demand reduces the FRC at the inlet, which results in lower condenser consumption of FRC.

The correlation coefficients when viewed with the regression model indicate that the condenser demand of FRC is highly dependent on the FRC level at the condenser inlet. The other factors in turn affect the FRC level at the condenser inlet and show up as being "related" to condenser demand.

Negative Consumption

In both Phases II and III, occurrences of "negative" consumption of FRC was noted. Since this may be an instrument error under certain circumstances, an analysis was carried out to identify any extreme conditions associated with the negative consumption. Table 20 shows factors which were significantly correlated with negative FRC condenser demand.

TABLE 20. FACTORS CORRELATED* WITH NEGATIVE FRC CONDENSER CONSUMPTION

Factor	Simple Correlation Coefficient
Conductivity	-0.48
Total Organic Carbon	-0.65
Total Nitrates-Nitrates	-0.53
Chlorine Dosage	-0.50

*Significant at the 0.10 level or smaller.

A regression model was developed to see which combination of factors explained the variation in negative condenser consumption of FRC. A model explaining 61 percent of the variation is:

$$\text{Neg} = -0.74 + 0.27\ \text{Free-In} - 0.89\ \text{NOX} + 0.01\ \text{ALKA} + 0.42\ CL_2 - .20\ CL_2^2$$

The model identifies alkalinity (ALKA) and total nitrates-nitrites (NOX) as significant factors. In addition, the chlorine dosage (CL_2) and the amount of FRC at the condenser inlet (Free-In) also have an effect on the negative condenser consumption of FRC (Neg). It should be noted that the Phase III analysis showed that only conductivity was a significant factor and that no regression model was adequate to explain the Phase III data. It would appear, therefore, that water quality is most closely connected with the apparent negative consumptions and that water quality parameters are highly interrelated. This in turn suggests that various compounds are being formed with the nitrogens which mask the true levels of FRC present. Therefore, this model should be used only as a general tool.

Chlorine Demand of the Water

Phase II data indicated a possible relationship between total organic carbon and the chlorine damand of the water. Phase III data showed that the 1-, 5-, and 10-minute demands were correlated with several factors which may directly affect the demand. Table 21 below shows those factors significant at the 0.10 level or smaller and the coefficients for Phases II and III data combined.

An attempt to explain the variation of the 1-minute demand with a regression model was unsuccessful in arriving at a model which explained a large portion of the variation. A stepwise regression procedure did put chlorine dosage, total organic carbon, and inlet water temperature in the model: but only 10 percent of the variation was explained.

The 5-minute demand was modeled as a function of the chlorine dosage and pH and explained 77 percent of the variation. The model was

$$D5 = -1.1958 + 0.4427\ CL_2 + 0.1218\ \text{pH}$$

with an error mean square of 0.0060 and the model F value of 71.55.

TABLE 21. FACTORS CORRELATED WITH CHLORINE DEMAND AND THE ASSOCIATED CORRELATION COEFFICIENTS

Factor	1 Minute	5 Minute	10 Minute
1. Chlorine Dosage	0.39	0.78	0.79
2. FRC at Condenser			
A. Inlet		0.25	0.40
B. Outlet		0.41	0.59
3. TRC at Condenser			
A. Inlet		0.49	0.61
B. Outlet		0.55	0.60
4. Inlet Water Temperature		0.39	
5. Conductivity	0.50	0.42	0.28
6. Alkalinity			-0.26
7. Total Suspended Solids		0.35	0.27
8. Total Organic Carbon		0.28	
9. Ammonia		-0.32	-0.37
10. Organic Nitrogen		-0.25	-0.30
11. Kjeldahl Nitrogen		-0.35	-0.41

Similarly, the 10-minute demand was modelled as a function of chlorine dosage and pH also. The model explained 67 percent of the total variation, with an error mean square of 0.0155 and a model F value of 42.81. The model is

$$D10 = -1.5820 + 0.5504\ CL_2 + 0.1627\ pH.$$

These models are consistent with what would be expected and has been observed in Phases II and III. Again, a note of caution on the models--since they are based on data gathered under two extremely different sets of conditions, they are to be used as a point of reference and discussion only.

Water Quality Parameters

The importance of water quality to a successful chlorine minimization/optimization study was recognized from the onset. However, identifying the significant water quality parameters during Phases I and II was extremely difficult due to the large variability induced by the faulty chlorinator. Only the extremely dominant factors could be identified in that situation. Phase III data, using the new chlorinator, allowed identification of significant water quality parameters. Particular ones have been mentioned earlier in this report where they had an effect on an item of interest. This section will take a more general overview.

Primarily due to the Phase III data, it has become apparent that the nitrogen compounds are directly involved with the chlorine chemistry. They are highly intercorrelated with each other and statistically, for a given analysis or model, one may be slightly more efficient than another. Alkalinity, conductivity, and total suspended solids are other water quality parameters affecting the chlorination mechanism. Surprisingly, pH does not show up often as being a significant factor. This may be due to its being highly correlated (negatively) with ammonia, but it is still surprising. The formation of byproducts which may "mask" the instrument detection of the true levels of free and total residual chlorine is directly dependent on the levels of the water quality parameters.

In order for a chlorine minimization program to succeed, these parameters must be monitored and their effects estimated since they affect the levels of FRC in the system and the ability of the instrumentation to accurately detect the FRC and TRC concentrations in the system.

Potential Lower Limits for Chlorination at John Sevier Steam Plant

The data from Phases I, II, and III have indicated that lower feed rates could be effective in maintaining adequate condenser performance. Based on a detailed examination of the data from all three phases, with particular emphasis on Phase III, potential lower limits of chlorine feed have been estimated for different ranges of inlet water temperature (see Table 22). These feed rates should result in an estimated average outlet FRC of 0.2 mg/l or less, which in turn would result in zero FRC being detected at the point of compliance. Thus, since the present standard is a 0.2 mg/l average FRC concentration, the feed rates may be set at some level above these lower limits and still produce a chlorine level within compliance limits. Based on Phase III data in fact, the recommended chlorination scheme met all standards at the point of compliance with no loss in condenser performance noted. So there appears to be no problem in meeting the present compliance limits.

TABLE 22. ESTIMATED LOWER LIMITS OF FEED RATES FOR CHLORINATION

Inlet Water Temperature	Feed Rates in Lbs/24 Hours
≤ 60°F	1500
60-75°F	2000
≥ 75°F	2500

Again, these are suggested lower limits which should be approached in an evolutionary operation with careful monitoring of condenser performance and the chlorine residual behavior. It is possible that somewhere between the present chlorination scheme and these estimated lower limits, there is a range of values of feed rates beneath which condenser performance could be adversely affected.

Justification for the recommended chlorine feed rates in Table 22 is found in the following scenario.

Table 23, which is in two parts, displays the FRC at the condenser inlet and outlet from Phase III when the recommended chlorination scheme was being followed and when it wasn't. Following the recommended chlorination scheme resulted in an average 0.28 mg/l FRC at the condenser inlet and 0.10 mg/l FRC at the condenser outlet. The minimum FRC at the inlet was 0.17 mg/l while the minimum outlet FRC was 0.05 mg/l. Based on a 0.1 to 0.2 mg/l of FRC at the condenser outlet as being necessary to maintain condenser performance for inlet water temperatures less than 55°F a feed rate of <1500 lbs/24 hours appears reasonable. For 55°-60°F, a feed rate of 1500-1800 lbs/24 hours looks achievable. Part B of the table indicates that a 2500 lbs/24 hours feed rate and a 3500 lbs/24 hours at inlet water temperatures of 50°F and 59.9°F, respectively, are too high since the average FRC at the inlet was 0.60 mg/l and at the outlet 0.46 mg/l.

TABLE 23. LOW INLET WATER TEMPERATURE CHLORINATION
TEMPERATURE <60°F.
<2000 LBS/24 HOURS RECOMMENDED

A. Following Chlorination Scheme

IWT	Date	Unit	Feed	FRC At Condenser Inlet	FRC At Condenser Outlet
37.4	2/3/78	3	1500	.30	.05
37.4	2/3/78	4	1500	.37	.13
53.6	3/24/78	2	1500	.29	.14
56.6	3/24/78	4	1500	.17	.07
			Means =	.28	.10

B. Not Following Chlorination Scheme

IWT	Date	Unit	Feed	FRC At Condenser Inlet	FRC At Condenser Outlet
59.0	10/17/78	1	2500	.51	.39
59.0	10/17/78	2	2500	.66	.61
59.9	5/16/78	2	3500	.25	.19
59.9	5/16/78	3	3500	.96	.66
			Means =	.60	.46

Table 24 summarizes the medium inlet water temperature chlorination scheme, which was set up as being between 60°F and 68°F. Average FRC at the inlet was 0.20 mg/l while an average outlet of 0.09 mg/l of FRC occurred. For inlet water temperatures of 60°-65°F, a lower limit in the range of 1800-2000 seems possible while a feed rate of 2000 lbs/24 hours seems necessary in the 65°F and warmer range.

TABLE 24. MEDIUM INLET WATER TEMPERATURE CHLORINATION
60°F ≤ TEMPERATURE ≤ 68°F. 2000-2500 LBS/24 HOURS RECOMMENDED

Following Chlorination Scheme

IWT	Date	Unit	Feed	FRC At Condenser Inlet	FRC At Condenser Outlet
62.6	4/13/78	2	1500	.25	.06
62.6	4/13/78	4	1500	.18	.04
62.6	4/13/78	3	2500	.24	.05
66.2	10/3/78	1	2500	.16	.12
66.2	10/3/78	3	2500	.17	.15
66.2	10/3/78	4	2500	.20	.13
			Means =	.20	.09

Table 25, Part A, shows a high inlet water temperature (>68°F) with a feed rate of 2500 lbs/24 hours. As the temperature of the inlet water increases, the FRC at the condenser inlet and outlet decrease. Part B, in conjunction with Table 24, Part C, indicates that in the range of 65°-70°F a feed rate of 2000-2300 lbs/24 hours may maintain adequate condenser performance.

Table 25, Part B, shows a feed rate of 3000-3500 lbs/24 hours at the high inlet water temperatures. In the range of 70°-75°F, feed rates in the range of 2300-2500 lbs/24 hours appear possible based on Parts A and B of Table 25. From 75°F and up, 2500 lbs or more appear necessary.

TABLE 25. HIGH INLET WATER TEMPERATURE CHLORINATION TEMPERATURE >68°F. 2500-3500 LBS/HOURS RECOMMENDED

A. Feed = 2500

IWT	Date	Unit	Feed	FRC At Condenser Inlet	FRC At Condenser Outlet
69.8	9/19/78	2	2500	.43	.37
69.8	9/19/78	3	2500	.41	.37
73.4	8/02/78	1	2500	.19	.16
73.4	8/02/78	2	2500	.31	.26
73.4	8/02/78	3	2500	.42	.31
73.4	8/02/78	4	2500	.43	.38
73.4	8/29/78	2	2500	.32	.19
73.4	8/29/78	3	2500	.44	.41
73.4	8/29/78	4	2500	.43	.38
75.2	7/18/78	2	2500	.15	.10
75.2	7/18/78	4	2500	.10	.09
75.2	8/08/78	4	2500	.11	.07
75.2	9/06/78	1	2500	.18	.17
75.2	9/06/78	2	2500	.23	.19
75.2	9/06/78	3	2500	.23	.20
75.2	9/06/78	4	2500	.28	.26
77.0	7/25/78	2	2500	.21	.17
77.0	7/25/78	3	2500	.18	.15
77.0	7/25/78	4	2500	.20	.18

B. Feed = 3000-3500

IWT	Date	Unit	Feed	FRC At Condenser Inlet	FRC At Condenser Outlet
68.9	6/06/78	1	3500	.55	.42
68.9	6/06/78	2	3500	.68	.30
68.9	6/06/78	3	3500	.66	.37
75.2	6/21/78	2	3000	.33	.32
75.2	6/21/78	3	3000	.45	.41
75.2	6/21/78	4	3000	.40	.39
75.2	6/27/78	1	3000	.49	.25
75.2	6/27/78	2	3000	.69	.34
75.2	6/27/78	3	3000	.59	.34
75.2	6/27/78	4	3000	.62	.29

SECTION 8

CHLORINATED ORGANICS

Introduction

The Environmental Protection Agency (EPA) has conducted tests for chlorinated organics at many major water treatment plants across the country. The resulting data led to the inclusion of many chlorinated organics on the priority pollutant list. Since then, many of these compounds have been shown to be carcinogenic to humans.

It has been assumed that these compounds are formed as a direct result of the chlorination process used by the water treatment plants. It is also assumed that these compounds are formed by the chlorination process used to reduce biofouling in the cooling water systems of fossil fuel and nuclear power plants. The power industry will have to comply with any limits on these compounds issued by EPA in their final criteria documents or in future criteria. Since many states having the authority to issue NPDES permits have a tendency to use these criteria as effluent guidelines and there are still questions regarding these compounds in chlorinated cooling water systems, it is imperative that uncertainties regarding the formation of these compounds in chlorinated cooling water systems be reduced.

As a result of EPA's tests, TVA examined the magnitude of chlorinated organics produced in a once-through cooling system. This was accomplished by defining the scope to determine: (1) the concentration of specific chlorinated organics that exist in the plants cooling water source; (2) compounds produced in the chlorination process and discharged by the plant; and (3) the relationship of compounds formed in the process to water quality.

To achieve these goals, field sampling and laboratory analysis of specific chlorinated organics taken from the priority pollutant list (see Table 26) were performed. This data enables TVA to determine if present chlorination practice is producing chlorinated organic priority pollutants above the concentrations defined in the draft water quality criterion documents published for review by EPA in 1978 and 1979.

Experimental Procedure

It was our intention to characterize the plant's condenser cooling water system for volatile and semivolatile chlorinated organics. This was accomplished by collecting water from the following points: intake, condenser inlet, and condenser outlet. The intake samples helped to determine what compounds and their concentrations are present before entering the plant. The inlet and outlet samples helped to determine what specific chlorinate organic compounds and their concentrations are being produced by the chlorination process of the plant.

TABLE 26. PRIORITY POLLUTANT LIST*

1.	Chlorobenzene	
2.	1, 2, 4 - Trichlorobenzene	
3.	Hexachlorobenzene	Chlorinated Benzenes
4.	Tetrachlorobenzene	
5.	Pentachlorobenzene	
6.	1, 2 - Dichlorobenzene	
7.	1, 3 - Dichlorobenzene	Dichlorobenzenes
8.	1, 4 - Dichlorobenzene	
9.	1, 2 - Dichloroethane	
10.	1, 1, 1 - Trichloroethane	
11.	Hexachloroethane	
12.	1, 1 - Dichloroethane	Chlorinated Ethanes
13.	1, 1, 2 - Trichloroethane	
14.	1, 1, 2, 2 - Tetrachloroethane	
15.	Chloroethane	
16.	Bis (Chloromethyl) Ether	
17.	Bis (2-Chloroethyl) Ether	Chloroalkyl Ethers
18.	2-Chloroethyl Vinyl Ether (mixed)	
19.	2-Chloronaphthalene	
20.	1, 1 - Dichloroethylene	Dichloroethylenes
21.	1, 2 - Trans-Dichloroethylene	
22.	Tetrachloroethylene	
23.	1, 2 - Dichloropropane	
24.	1, 3 - Dichloropropylene (1, 2 Dichloropropene)	
25.	2, 4, 6 - Trichlorophenol	
26.	2, 4 - Dichlorophenol	
27.	2 - Chlorophenol	
28.	3 - Chlorophenol	
29.	4 - Chlorophenol	
30.	Trichlorophenol	Chlorinated Phenols
31.	Tetrachlorophenol	
32.	Pentachlorophenol	
33.	Dichlorophenol	
34.	Chloroform	
35.	Methylene Chloride	
36.	Methyl Chloride	
37.	Methyl Bromide	
38.	Bromoform	Halomethanes
39.	Dichlorobromomethane	
40.	Trichlorofluoromethane	
41.	Dichlorodifluoromethane	
42.	Chlorodibromomethane	
43.	Bromodichloromethane	
44.	Carbon Tetrachloride	
45.	Mono-Chlorocresols	
46.	Di-Chlorocresols	
47.	Tri-Chlorocresols	
48.	Tetra-Chlorocresols	

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*Compiled from the 129 List of EPA.

The chlorination process is a major factor contributing to the formation of chlorinated organics. Therefore, samples were taken during the chlorination cycle to determine: (1) if the formation is instantaneous or if there is a time interval before the formation begins; and (2) what compounds and their concentrations are formed. The sampling schedule (see Table 27) was determined based on a 20-minute chlorination cycle.

TABLE 27. SAMPLING SCHEDULE

Intake	- Before chlorination cycle
Condenser Inlet	- 8 minutes into chlorination cycle
Condenser Outlet	- 8 minutes into chlorination cycle
Condenser Outlet	- 16 minutes into chlorination cycle
Condenser Outlet	- 5 minutes after chlorination cycle has ended
Intake	- After chlorination cycle

All samples were collected and immediately cooled to 4°C by packing them in ice. The samples were transported to the labroatory for analysis.

The presampling preparation and sampling procedures were the techniques set down by the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio,[15] and the TVA Office of Natural Resources, Laboratory Branch.

Conclusions and Recommendations

Based on the data gathered in this study, the following conclusions and recommendations are presented:

Conclusions--

1. Chlorinated organics were found at the condenser inlet and outlet in measurable levels. The largest single measurement was less than 10 μg/l.

   The following compounds were identified: chloroform, bromodichloromethane, and dibromochloromethane. On the average, these compounds were measured at 5.7 μg/l chloroform, 2.4 μg/l bromodichloromethane, and 0.83 μg/l for dibromochloromethane.

2. Chlorine dosage appears to be directly related to the level of chloroform concentration and dibromochloromethane concentrations observed. Bromodichloromethane formation does not appear to be as strongly influenced by the chlorine dosage.

3. While chlorine dosage appears to be the main driving force in the formation of chloroform and dibromochloromethane, the possiblity of a secondary reaction between the two compounds appears likely. This factor should be considered in future studies.

4. Other factors, which could not be identified with the data at hand, also influenced the formation of chlorinated organics. It is suspected that some of these factors are pH, water temperature, water quality, organic precursors, amino acids, and time. These factors will be studied in future projects.

5. The formation of dibromochloromethane appears to occur after chloroform and bromodichloromethane formation.

Recommendations

A more intense study should be performed on chlorinated organics. This study should focus on the relationship of water quality, organic precursors and amino acids to chlorinated organics.

Discussion

This section will be divided into three parts: (a) chloroform, (b) bromodichloromethane, and (c) dibromochloromethane.

Chloroform--

The formation of chloroform appears to be instantaneous. This compound was detected at the condenser inlet shortly after chlorination began. The largest average chloroform concentration occurred five minutes into the chlorination cycle at the condenser inlet and averaged 5.70 μg/l. At the condenser outlet, 8 and 16 minutes into the chlorination cycle, average chloroform concentrations of 5.67 μg/l occurred. The largest observed chloroform concentration was 9.3 μg/l at the condenser inlet on November 15, 1978, and the smallest was below detection limits at the condenser inlet on November 1, 1978. Table 28 summarizes these results. Chloroform was not detected in the unchlorinated raw river water.

TABLE 28. CHLOROFORM CONCENTRATIONS ($\mu g/l$)

Date	Condenser Inlet 5 minutes into Cycle	Condenser Outlet 8 Minutes into Cycle	Condenser Outlet 16 Minutes into Cycle
11/01/78	<1.0	7.1	7.1
10/03/78	3.2	4.0	3.9
01/09/79	3.3	7.3	6.5
08/29/78	4.8	5.4	5.2
11/29/78	4.9	5.5	5.2
01/23/79	8.7	5.9	5.4
11/15/78	9.3	8.7	8.4
07/25/78	-	3.8	4.1
09/19/78	-	3.2	5.2
Average	5.70	5.67	5.67

There was a definite relationship between the chlorine dosage (mg/l) and the chloroform concentration. The average change in chloroform in $\mu g/l$ in response to a change in chlorine dosage in mg/l was approximately five to one at the condenser outlet eight minutes into the chlorination cycle and three to one 16 minutes into the chlorination cycle. For example, if the chlorine dosage increased 0.2 mg/l, then the chloroform concentration eight minutes into the cycle increased 1.0 $\mu g/l$ at the condenser outlet and 0.6 $\mu g/l$ 16 minutes into the cycle. Due to the large variability in the data, these ratios must be regarded with caution. Also, the large variability associated with the levels of chlorine dosage indicate that other factors are affecting the chloroform concentration. It is suspected, although collaborative data were not available, that pH, water temperature and/or other constituents in the cooling water are the source of this variability.

Based on the data collected, chlorine dosage was not the dominant factor in the formation of chloroform at the condenser inlet. This is not to say chlorine dosage does not affect chloroform formation at the condenser inlet; but it is probably equivalent in magnitude to other factors such as pH, water quality, temperature and time.

The concentration of bromodichloromethane was compared to the chloroform concentration. In general, the amount of bromodichloromethane formed averaged approximately 38-42 percent of the chloroform concentration in $\mu g/l$. Table 29 summarizes the data.

Table 30 presents the ratio of chloroform concentration to dibromochloromethane. One noticable feature was the increase in dibromochloromethane after the chlorine pulse passed through the system. This indicated that the development of dibromochloromethane lags behind the formation of chloroform and bromodichloromethane.

TABLE 29. CHLOROFORM ($CHCl_3$) AND BROMODICHLOROMETHANE ($CHCl_2Br$) FORMATION ($\mu g/l$)

	Condenser Inlet 5 Minutes into Cycle			Condenser Outlet 8 Minutes into Cycle			Condenser Outlet 16 Minutes into Cycle		
Date	$CHCl_3$	$CHCl_2Br$	Ratio[1]	$CHCl_3$	$CHCL_2Br$	Ratio[1]	$CHCl_3$	$CHCl_2Br$	Ratio[1]
11/01/78	<1.0	<0.2	<0.20	7.1	3.8	0.54	7.1	3.3	0.4
12/03/78	3.2	1.7	0.53	4.0	2.1	0.53	3.9	2.0	0.5
01/09/79	3.3	1.7	0.52	7.3	1.1	0.15	6.5	1.0	0.15
08/29/78	4.8	1.2	0.25	5.4	1.4	0.26	5.2	1.4	0.25
11/29/78	4.9	3.2	0.65	5.5	3.5	0.64	5.2	3.4	0.65
01/23/79	8.7	<0.2	<0.02	5.9	1.0	0.17	5.4	0.9	0.17
11/15/78	9.3	4.2	0.45	8.7	4.6	0.53	8.4	4.4	0.52
07/25/78	-	-	-	3.8	1.3	0.34	4.1	1.4	0.34
09/19/78	-	-	-	3.2	1.0	0.31	5.2	1.6	0.31
AVERAGE	5.70	2.40	0.42	5.67	2.20	0.39	5.67	2.16	0.38

[1] Ratio = $CHCl_2Br/CHCl_3$

TABLE 30. CHLOROFORM ($CHCl_3$) AND DIBROMOCHLOROMETHANE ($CHClBr_2$) FORMATION ($\mu g/l$)

	Condenser Inlet 5 Minutes into Cycle			Condenser Outlet 8 Minutes into Cycle			Condenser Outlet 16 Minutes into Cycle		
Date	$CHCl_3$	$CHClBr_2$	Ratio[1]	$CHCl_3$	$CHCLBr_2$	Ratio[1]	$CHCl_3$	$CHClBr_2$	Ratio[1]
11/01/78	<1.0	<0.2	<0.20	7.1	1.1	0.15	7.1	0.9	0.15
12/03/78	3.2	0.7	0.22	4.0	0.8	0.20	3.9	0.6	0.15
01/09/79	3.3	<0.2	<0.06	7.3	1.7	0.23	6.5	1.7	0.26
08/29/78	4.8	0.2	0.04	5.4	0.3	0.06	5.2	0.2	0.04
11/29/78	4.9	1.1	0.22	5.5	1.2	0.22	5.2	1.3	0.25
01/23/79	8.7	0.2	0.02	5.9	0.3	0.05	5.4	<0.2	<0.04
11/15/78	9.3	1.3	0.14	8.7	1.5	0.17	8.4	1.4	0.17
07/25/78	-	-	-	3.8	0.3	0.08	4.1	0.3	0.07
09/19/78	-	-	-	3.2	0.2	0.06	5.2	0.2	0.04
AVERAGE	5.70	0.70	0.12	5.67	0.82	0.14	5.67	0.83	0.15

[1] Ratio = $CHClBr_2/CHCl_3$

As can be seen, chloroform is the most abundant priority pollutant produced in the cooling water system during chlorination. In future studies an attempt will be made to identify the other variables involved in the formation of chloroform.

Bromodichloromethane--

Bromodichloromethane was the second most abundant priority pollutant produced in the cooling water system during chlorination. The largest average bromodichloromethane concentration occurred at the condenser inlet five minutes into the chlorination cycle and averaged 2.40 μg/l. The average concentrations at the condenser outlet 8 and 16minutes into the chlorination cycle were 2.20 μg/l and 2.16 μg/l, repectively. Table 31 summarizes these results.

TABLE 31. BROMODICHLOROMETHANE CONCENTRATIONS (μg/l)

Date	Condenser Inlet 5 Minutes into Cycle	Condenser Outlet 8 Minutes into Cycle	Condenser Outlet 16 Minutes into Cycle
11/01/78	<0.2	3.8	3.3
11/23/79	<0.2	1.0	0.9
09/29/78	1.2	1.4	1.4
10/03/78	1.7	2.1	2.0
01/09/78	1.7	1.1	1.0
00/29/78	3.2	3.5	3.4
11/15/78	4.2	4.6	4.4
11/25/78	-	1.3	1.4
09/19/78	-	1.0	1.6
AVERAGE	2.40	2.20	2.16

The formation of bromodichloromethane and dibromochloromethane appear to be strongly related according to the data analysis. The dibromochloromethane was approximately 28-32 percent of the concentration of bromodichloromethane. This average was fairly stable at both the condenser inlet and outlet. Table 32 summarizes this data.

TABLE 32. BROMODICHLOROMETHANE ($CHCl_2Br$) AND DIBROMOCHLOROMETHANE ($CHClBr_2$) FORMATION (μg/l)

	Condenser Inlet 5 Minutes into Cycle			Condenser Outlet 8 Minutes Into Cycle			Condenser Outlet 16 Minutes into Cycle		
Date	$CHCl_2Br$	$CHClBr_2$	Ratio[1]	$CHCl_2Br$	$CHClBr_2$	Ratio[1]	$CHCl_2Br$	$CHClBr_2$	Ratio[1]
11/01/78	<0.2	<0.2	<1.00	3.8	1.1	0.29	3.3	0.9	0.27
01/23/79	<0.2	0.2	>0.20	1.0	0.3	0.33	0.9	<0.2	<0.2
08/29/78	1.2	0.2	0.17	1.4	0.3	0.21	1.4	0.2	0.14
10/03/78	1.7	0.7	0.41	2.1	0.8	0.38	2.0	0.6	0.3
01/09/79	1.7	<0.2	<0.12	1.1	1.7	1.55	1.0	1.7	1.7
11/29/78	3.2	1.1	0.34	3.5	1.2	0.34	3.4	1.3	0.38
11/15/78	4.2	1.3	0.31	4.6	1.5	0.33	4.4	1.4	0.32
01/25/78	-	-	-	1.3	0.3	0.23	1.4	0.3	0.21
09/19/78	-	-	-	1.0	0.2	0.20	1.6	0.2	0.13
AVERAGE	2.40	0.70	0.32	2.20	0.82	0.30[2]	2.16	0.83	0.28

[1] Ratio = $CHClBr_2/CHCl_2Br$

[2] Average ratio does not include 1/9/79 data

The strong relationship between bromodichloromethane and dibromochloromethane may be due to each being strongly related to other factors such as chlorine dosage, water temperature, water quality, pH, and time. But, collaborative data were not available.

Dibromochloromethane--

Table 33 summarizes the occurrence of dibromochloromethane. The largest average dibromochloromethane concentration was 0.83 μg/l occurring at the condenser outlet 16 minutes into the chlorination cycle.

TABLE 33. DIBROMOCHLOROMETHANE CONCENTRATIONS (μg/l)

Date	Condenser Inlet 5 Minutes into Cycle	Condenser Outlet 8 Minutes into Cycle	Condenser Outlet 16 Minutes into Cycle
11/01/78	<0.2	1.1	0.9
01/09/79	<0.2	1.7	1.7
08/20/78	0.2	0.3	0.2
01/23/77	0.2	0.3	<0.2
10/03/78	0.7	0.8	0.6
11/29/78	1.1	1.2	1.3
11/15/78	1.3	1.5	1.4
07/25/78	-	0.3	0.3
09/19/78	-	0.2	0.2
AVERAGE	0.70	0.82	0.83

There was a definite relationship between the chlorine dosage (mg/l) and the dibromochloromethane concentration. However, variability of the data around this relationship indicated that other factors were also having an effect on the formation of dibromochloromethane.

These three compounds have been identified in the cooling water systems during chlorination. Samples were collected after chlorination had ended and none of these compounds were identified. At the low concentration levels of these compounds, they do not appear to pose a problem to the receiving stream.

SECTION 9

CONDENSER PERFORMANCE SENSITIVITY STUDY

Introduction

In Section 4 the calculation of condenser performance as formulated by the Heat Exchange Institute (HEI) and the American Society of Mechanical Engineers (ASME) was discussed. This method is a steam-side calculation. TVA has developed a method of calculating the condenser performance by closing the heat balance on the water side of the condenser. While this new method is much easier to use, it still contains many of the same variables which effect the steam-side calculations. In addition, this new method should only be used for a "quick" check on condenser performance. The HEI and ASME method should still be used for reporting condenser performance. While this new method was not used during the study at John Sevier, it did support the relationship of inlet water temperature to condenser performance developed in the statistical analysis.

Equation Derivation

Condenser performance, otherwise known as the apparent cleanliness factor (ACF), is the relationship of the measured heat transfer coefficients (HTC (U)) of a used tube to a new tube.

$$\text{ACF} = \frac{U_o}{U_n} \tag{1}$$

$$\text{Measured HTC} = \frac{q}{\text{CSA} \cdot \text{LMTD} \cdot k} \tag{2}$$

where: q = condenser duty
CSA = condenser surface area
k = design correction factor
LMTD = logarithmic mean temperature difference

$$\text{LMTD} = \frac{\Delta T}{\log_e \dfrac{t_s - t_1}{t_s - t_2}} \tag{3}$$

then: HTC = U = $C\sqrt{\text{velocity}}$ where C depends on tube diameter. For a 7/8- to 1-inch tube diameter, C=263.

therefore:

$$\text{ACF} = \frac{q}{\text{CSA} \cdot \text{LMTD} \cdot k \cdot U} \tag{4}$$

where:

$$\text{LMTD} = \frac{\Delta T}{\log_e \dfrac{t_s - t_1}{t_s - t_2}}$$

t_2 = outlet water temperature

t_1 = inlet water temperature

t_s = inlet steam temperature, corresponding to the steam pressure $(1.2263 - 0.002067\ t_1)$

$$k = \frac{t_1}{100} \qquad (5)$$

for $40° \leq t_1 \leq 85°\text{F}$

$$1\ \text{gpm} = 0.002228\ \text{ft}^3/\text{sec} = 500\ \text{lb/hr} \qquad (6)$$

Using equation 6, $q = 500 \cdot \Delta T \cdot$ cooling water flow (7)

Using equation 6, the tube velocity $= \dfrac{q}{\text{CCSA}} \times \dfrac{0.002228}{\Delta T \times 500}$ (8)

where: CCSA = condenser cross-section area

By substituting equations 5, 7, and 8 into equation 4, the apparent cleanliness factor becomes:

$$\text{ACF} = \frac{500}{12.4140} \times \frac{\sqrt{\text{CCSA}}}{k \times \text{CSA}} \times \text{CCW flow} \times \log_e \frac{t_s - t_1}{t_s - t_2} \qquad (9)$$

This equation can be simplified to the following:

$$\text{ACF} = 40.277 \times \frac{\sqrt{\text{CCSA} \times \text{CCW}} \times \log_e \dfrac{t_s - t_1}{t_s - t_2}}{k \times \text{CSA}} \qquad (10)$$

Therefore, for a given condenser, it can be observed that the inlet water temperature can alter the ACF. Figure 12 depicts the trend of ACF vs. inlet water temperature.

The design correction factor, k, was modeled based on the values obtained from the TVA computer program of the HEI calculation. The equation developed was:

$$\log_e k = (1.2263 - 0.002067\ t_1) \log_e t_1 - \log_e 100 \qquad (11)$$

where: $t_1 = 40°\text{F} \leq t_1 \leq 5°\text{F}$

The correlation coefficient calculated using the HEI calculation versus equation 11 is 0.999. A graph of k versus inlet water temperature may be found in Figure 13. The design correction factor is 1 at 70°F inlet water temperature. Therefore, the ACF will best measure tube fouling at 70°F. At other temperatures, the ACF measures both the fouling of the tubes and the inherent change of ACF with inlet water temperature.

Looking at Figure 12, it can be seen that at 85°F inlet water temperature the ACF is 0.8 rather than 0.85 at 70°F. This relationship is solely due to inlet water temperature. Conversely, at 60°F the ACF is approximately 0.9. Again, this relationship is solely due to inlet water temperature. This analysis confirms the statistical analysis previously performed and shows a linear estimate of a 3°F change in inlet water temperature results in a 1.2 percentage point change in ACF. The previous statistical analysis reported a 1 percentage point change in ACF for a 3°F change in inlet water temperature.

The model for ACF has been programmed in BASIC and is routinely run on a Tektronix 4050 series computer.

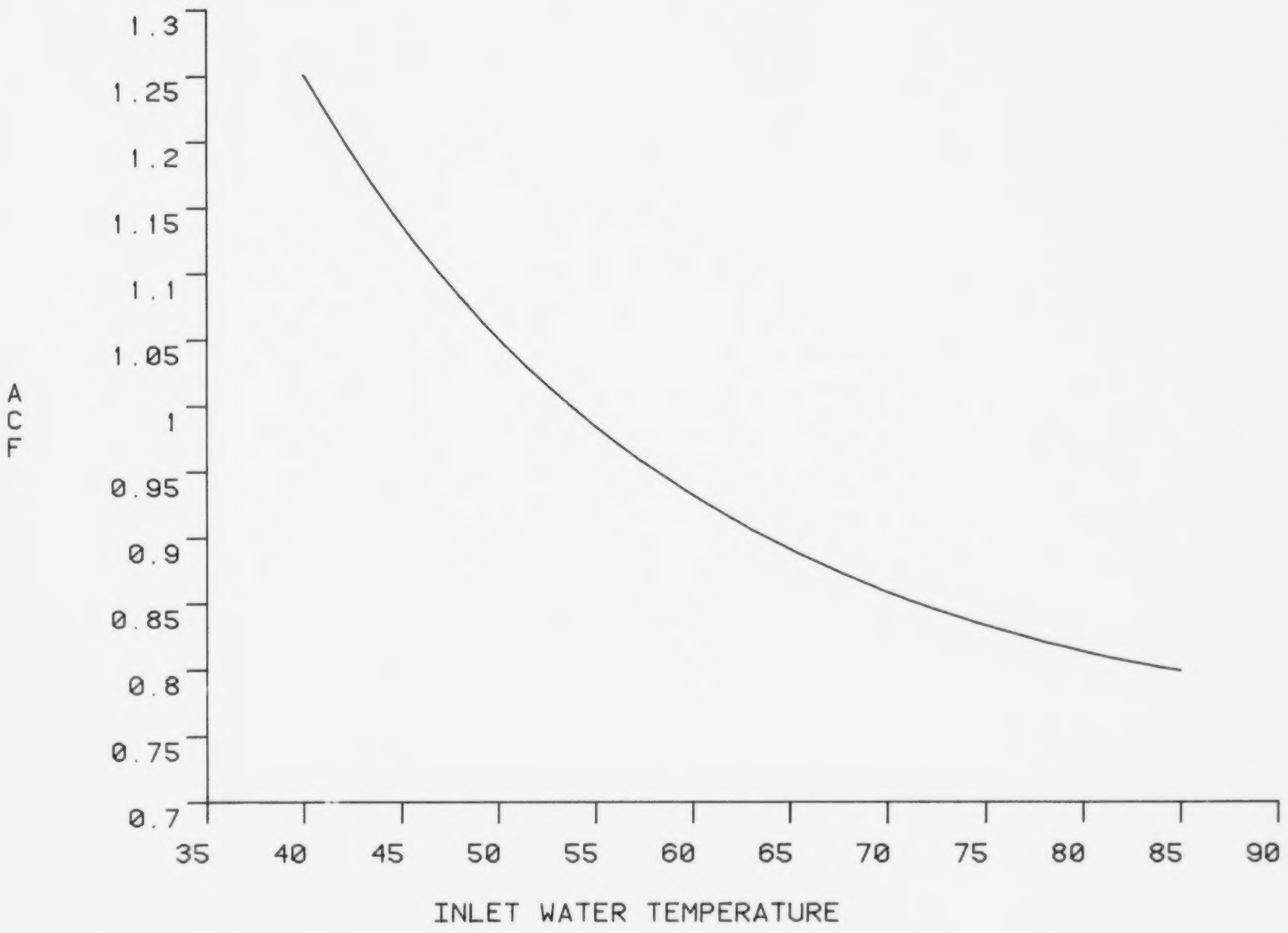

Figure 12. Apparent cleanliness factor vs. inlet water temperature

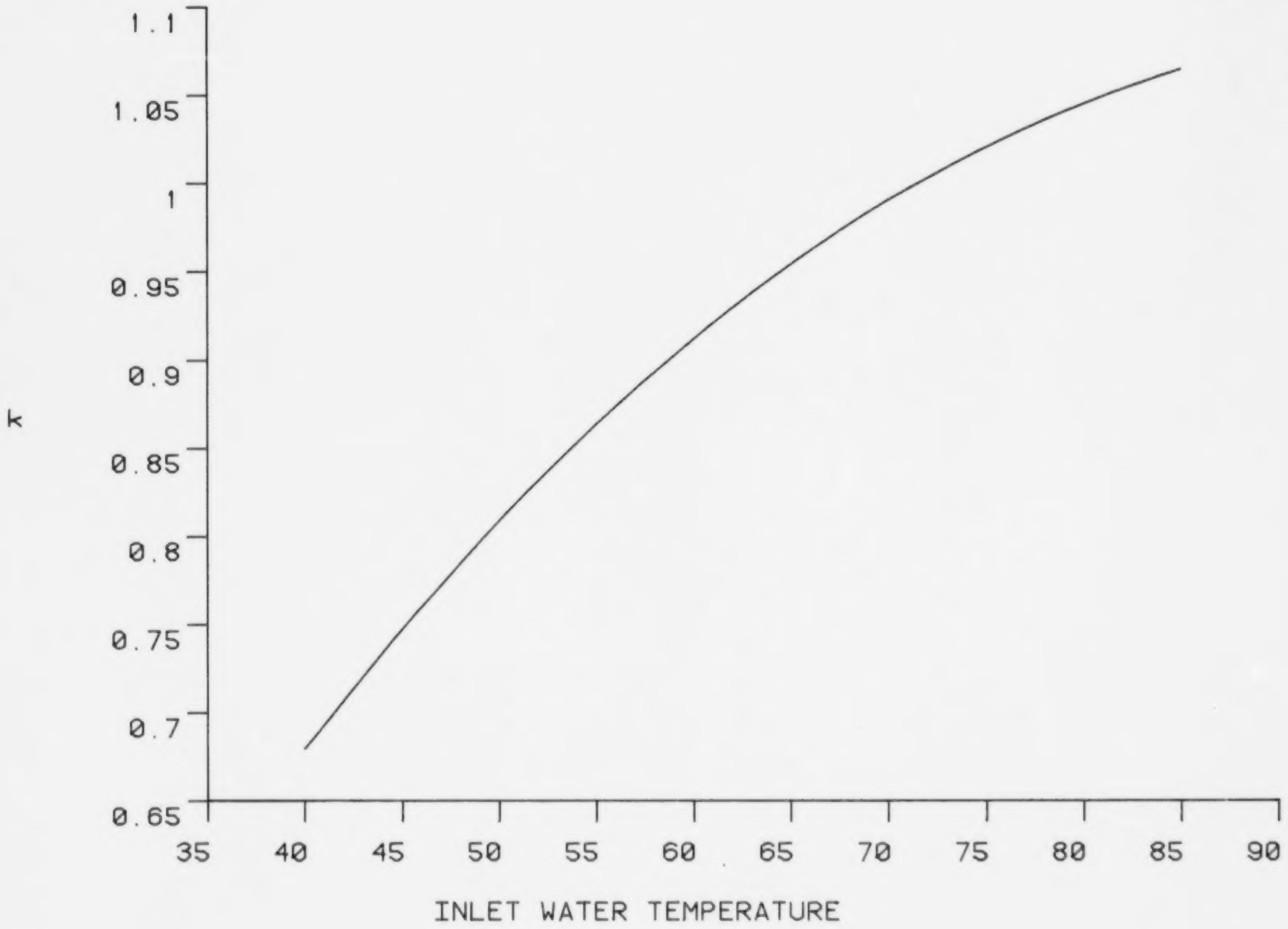

Figure 13. Design correction factor vs. inlet water temperature

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APPENDIX A

ANALYSIS OF PHASE II CHLORINATION STUDY DATA

APPENDIX A

I. INTRODUCTION

This report documents the data and its analysis from the chlorine minimization/optimization project which was conducted at the John Sevier Steam Plant in compliance with EPA effluent guidelines and National Pollutant Discharge Elimination System (NPDES) permits. Phase II, conducted during the summer of 1977, focused on the factors affecting condenser performance, free and/or total residual chlorine consumption in the system, and the relationship between inlet water temperature and variables associated with chlorine use such as turbine backpressure, total nitrogen, total organic carbon, and chlorine demand. Phase III, conducted from October 1977 to December 1978, focused on a verification of the Phase II conclusions and provided further information concerning the relationships connected with lower levels of chlorination and associated parameters, such as inlet water temperature, Kjeldahl nitrogen, turbine backpressure, and pH.

The objective of the analysis of the data was to broaden the understanding of the characteristics for the system affecting chlorine use while identifying more precisely the operating conditions to maintain adequate condenser performance with low concentrations of chlorine in the effluent. The factors affecting the interpretation of the statistical results and the examination of the results of the condenser performance, chlorine consumption, and chlorine in effluent analyses in terms of the overall objective are denoted below.

A. Significant Sources of Variation

During the analysis of the data, it became evident that significant sources of variation existed which affected the interpretations and conclusions drawn from the data. The variability of the chlorinator, the inherent error in the measurement technique of chlorine, and the variation induced by inlet water temperature were adjusted, if possible, or recognized and considered when interpreting the results.

B. Some Statistical Considerations

Wherever possible considerable cross-checking of estimates such as means, variances, and standard errors was done. In order to have balance in some of the analyses, some data points were not used but were included in the cross-checking. Some of the raw data were obviously in error, such as extremely negative chlorine consumption in the system, and not used at all.

For most of the analyses, the error mean square was fairly consistent (after adjusting for unequal sample sizes)--usually about 0.02.

The scheduled test program for Phase II included 20 test dates. The feed rate was 4500 lbs/24 hours for May through July , 3000 lbs/24 hours for August, and 2500 lbs/24 hours for September. As the raw data in Appendix B indicate, some minor departures from the schedule took place. The frequency and rate of chlorine feed to each condenser were as follows:

Unit 1: Twice per day for 1 hour each (control)
Unit 2: Twice per day for 30 minutes each
Unit 3: Three times per day for 20 minutes each
Unit 4: Six times per day for 10 minutes each

This test schedule was designed so that the fixed feed rate for May through July would allow estimation of time effects, frequency and duration of chlorine feed rates. The frequency and duration of feeds at the various condensers allow a comparison of the effects of frequency and duration of feed rates. The August and September data allow estimation of the differences in feed rates as compared with varying the other factors.

Results indicated that adequate condenser performance could be maintained with low concentrations of chlorine in the effluent if the chlorine feed is three times per day for 20 minutes each with approximately the following feed rates for different levels of inlet water temperature and assuming that there is no drastic change in seasonal chlorine demand:

(1) 2500 - 3000 lb/24 hours for inlet water temperatures of 68°F or more;

(2) 2000 - 2500 lb/24 hours for inlet water temperatures between 60°F and 68°F; and

(3) less than 2000 lb/24 hours for inlet water temperatures less than 60°F.

In addition, on nine test dates outlet free and total residual chlorine were measured by the DPD and amperometric methods. These data were gathered to allow a comparison of the two methods.

The scheduled test program for Phase III was for 36 test dates. The feed rate was adjusted according to the inlet and outlet FRC concentrations, inlet water temperature, chlorine demand, and condenser performance.

Based on the Phase III analysis, some apparent contrasts were noted when comparing the data with Phase II. While the feed rates were run at considerably lower levels in Phase III than in Phase II, the mean apparent cleanliness factor (ACF) was slightly higher in spite of higher inlet water temperatures. While not significantly higher, this does reinforce the justification for the chlorination scheme which maintains adequate condenser performance at lower feed rates. Another factor noted was the significant decrease in experimental error in the data. This was probably due to the improved performance of the new chlorinator.

As a result of the Phase III analysis, the following lower limits of feed rate for various intervals of inlet water temperature might be achievable:

Table A-1

FEED RATE AS A FUNCTION OF INLET WATER TEMPERATURE

Inlet Water Temperature (°F)	Chlorine Feed Rate (Lbs/24 hrs)
$\leq$60°F	1500
60-75°F	2000
$\geq$75°F	2500

These values should be approached cautiously in an evolutionary operation with careful monitoring of condenser performance and the chlorine residual behavior.

II. CONDENSER PERFORMANCE

A. Discussion

Condenser performance is measured by the apparent cleanliness factor (ACF) as calculated by the Heat Exchange Institute.* The main concern was the effect of different chlorination rates and frequency and duration of feed on the apparent cleanliness factor. Compounding the analysis problem was inlet water temperature variation, which is related to the apparent cleanliness factor. An analysis of covariance with inlet water temperature as the covariate was performed.

The analysis of condenser performance, adjusting for the effects of inlet water temperature, assumed that the apparent cleanliness factor was a linear function of feedrate and "unit factor" with an interaction. Although there are many other factors which influence ACF, we are limiting these factors for statistical purposes.

"Unit factor" is the effect of frequency and duration of feed. Since the effects of frequency and duration of feed were mixed or confounded with the units, special comparisons or contrasts of the unit means were made to estimate the effects of varying frequency and the duration of feed.

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*This method of calculating the ACF is widely used throughout the utility industry. It must be carefully noted, however, that the ACF only approximates the true condenser performance. Thirty-seven variables are used in the steam-side calculation so it must not be construed as absolute. Such variables as inlet water temperature, turbine back pressure, gross generation, condenser duty, and air leakage will greatly affect the results of this calculation. For further explanation of ACF, please refer to Section 4 and Appendix J.

B. Phase II

Table A-2 summarizes the analysis. Note that feed rate, "unit factor," and their interaction were significant. Table A-3 presents the adjusted ACF means.

TABLE A-2

ANALYSIS OF APPARENT CLEANLINESS FACTOR (AFTER ADJUSTING FOR INLET WATER TEMPERATURE)

Source	DF	Sum of Squares	Mean Square	F Value
Feed Rate	1	0.0091	0.0091	73.88*
Unit	3	0.0076	0.0025	20.53*
Interaction	3	0.0039	0.0013	10.55*
Inlet Water Temperature	1	0.0004	0.0004	3.49*
Error	15	0.0018	0.0001	
Corrected Total	23	0.0228		

*Significant

TABLE A-3

MEAN VALUES OF APPARENT CLEANLINESS FACTOR AFTER ADJUSTING FOR INLET WATER TEMPERATURE

Feed Rate (lb/24 hrs.)*	Unit			
	1	2	3	4
4,500	.7351	.7364	.7549	.7549
1,500	.6861	.7516	.7641	.7756

*This is only a relative feed rate. The absolute FRC concentration is not constant from day to day at the inlet to the condenser due to changing levels of chlorine demand and cooling water flow.

Testing for interaction effects yielded a significant interaction effect. While it was smaller than the main effects, it did indicate that the proper model was not additive in its effects. Interpretation of the interaction effect was difficult due to the effect of duration of feed being completely confounded with the unit effects. Examination of the adjusted mean apparent cleanliness factors indicates that at the lower feed rate, as the frequency of feed increases while the duration is lowered, the response of condenser performance increases more rapidly than the pure addition of feed rate and "unit factor."

A comparison of the mean apparent cleanliness factors for each feed rate was made to examine the means and the differences between them for Units 3 and 4 combined. Two considerations were made in choosing the appropriate error mean square. First, because an analysis of covariance was carried out, an allowance for the sampling error of the regression coefficient was made. Secondly, the unequal sample sizes for the two feed rates were factored in. The comparison showed the lower feed rate had a significantly higher apparent cleanliness factor.

A comparison of the average apparent cleanliness factors for each unit was made to determine the differences between units. Comparisons were made to determine the direction of change necessary in frequency and duration of feed to increase condenser performance. Estimating the appropriate error mean square for the comparisons was simpler because the sample size (six good data points) was equal for each unit. To evaluate the effects of varying frequency, the average of Units 1 and 2 (which had the same frequency) were contrasted with the means of Unit 3 and Unit 4, respectively. The comparisons showed that Unit 3 and Unit 4 had significantly higher condenser performance than the average of Units 1 and 2. The higher condenser performance of Units 3 and 4 was not solely attributed to the change in frequency alone as there may have been unit differences and duration of feed differences. Since Units 1 and 2 had the same frequency but different durations of feed, the response of condenser performance was indicated by comparing Units 1 and 2. The difference between Units 1 and 2 condenser performance was significant, with the lower interval of duration having significantly higher condenser performance. Units 3 and 4 were not significantly different from each other, but were significantly higher than Units 1 or 2.

Significantly better condenser performance was achieved by using a lower feed rate more frequently with a shorter duration of feed than a higher feed rate less frequently for longer durations of feed. Units 3 and 4 were not significantly different from each other indicating that either the combination of feeding three times a day for 20 minutes or 6 times a day for 10 minutes will result in adequate condenser performance.

1. Statistical Analysis

a. Comparing Feed Rates, Adjusting for Inlet Water Temperature, Similar Units

Mean ACF for a feed rate of 4500 lbs/24 hours (adjusted for inlet water temperature) based on 8 data points = .7549. Mean ACF for a feed rate of 1500 lbs/24 hours (adjusted for inlet water temperature) based on 4 data points = .7699.

Comparison = ..599 - .7549 = .0150
Error Mean Square of the Comparison = .0067
T = .0150/.0067 = 2.24

This comparison is significant at the 0.10 level.

b. Comparing Changes in Frequency and Duration of Feed

	Adjusted for Inlet Water Temperature
Unit 1 mean ACF =	.7189
Unit 2 mean ACF =	.7414
Unit 3 mean ACF =	.7579
Unit 4 mean ACF =	.7618

(1) Unit 3 versus the average of Units 1 and 2:

Comparison = .7579 - ((.7189 + .7414)/2) = .0278
Error Mean Square of the Comparison = .0049
T = .0278/.0049 = 5.67

There is a 90 percent confidence that Unit 3 data are significantly different from those of Units 1 and 2.

(2) Unit 4 versus the average of Units 1 and 2:

Comparison = .7618 - ((.7189 + .7414)/2) = .0317
Error Mean Square of the Comparison = .0049
T = .0317/.0049 = 6.46

There is a 90 percent confidence that Unit 4 data are significantly different from those of Units 1 and 2.

(3) Unit 2 versus Unit 1:

Comparison = .7414 - .7189 = .0225
Error Mean Square = .0057
T = .0225/.0057 = 3.95

There is a 90 percent confidence that Unit 2 data are significantly different from Unit 1 data.

(4) Unit 4 versus Unit 3:

Comparison = .7618 - .7579 = .0039
Error Mean Square = .0057
T = .0039/.0057 = 0.68

This comparison is not significant.

(5) Unit 4 versus Unit 2*

Comparison = .7618 - .7414 = .0204
Error Mean Square = .0057
T = .0204/.0057 = 3.58

There is a 90 percent confidence that Unit 4 data are significantly different from Unit 2 data.

C. Phase III

The Phase III chlorination study had an average apparent cleanliness factor (ACF) of 77. The ACF for the Phase II data was 74. Given that the average inlet water temperature for Phase II was 68°F and 61°F for Phase III, it is easily seen that the present chlorination scheme has not had a detremental effect on condenser performance as measured by ACF. Since a 3° rise in temperature results in about a 1 percent change in ACF, the two ACF's are equivalent (within experimental error) on a temperature-adjusted basis.

D. Turbine Backpressure

1. Behavior After Tube Cleaning

There was insufficient data from Phase III to realistically evalute if a drop in turbine backpressure occurred consistantly after tube cleaning.

2. Relationship to Inlet Water Temperature

A detailed analysis has conclusively identified the role of inlet water temperature and other factors to turbine backpressure and apparent cleanliness factors. See Section 8 for further details.

III. CHLORINE CONSUMPTION

A. Discussion

This section discusses the behavior of the system consumption of free and total residual chlorine. The system consumption was estimated by subtracting the amount of chlorine at the outlet of the condenser from the chlorine concentration at the intake.

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*No comparison of Units 3 and 2 is necessary since there is no significant difference between Units 4 and 3.

B. Phase II - System Consumption of Free and Total Residual Chlorine

1. Fixed Feed Rate

Data gathered for May, June, and July with the units operating at a feed rate of 4500 lbs/24 hours allowed evaluation of the time and operating conditions for a fixed feed rate. For both free and total residual chlorine, there was no significant difference in consumption over the time period of the data.

There was no significant correlation between FRC consumption and inlet water temperature on any unit. However, there was a statistically significant negative correlation between TRC consumption and inlet water temperature for units 2 and 3, and a nonsignificant positive correlation between TRC consumption and inlet water temperature for units 1 and 4. For units 2 and 3, TRC consumption tends to decrease as inlet water temperature increases. The correlations always had the same sign (either both positive or both negative) for FRC and TRC consumption with inlet water temperature on each unit.

This negative relationship between inlet water temperature and TRC consumption for Units 2 and 3 should be treated with caution until all data have been analyzed.

As Table A-4 indicates, reducing the duration of feed and increasing the frequency of feed tends to increase chlorine consumption for the fixed feed rate. However, the difference between units was not significant for either FRC or TRC consumption.

TABLE A-4

MEANS OF FREE AND TOTAL RESIDUAL CHLORINE
CONSUMPTION (mg/l) BY UNIT
(FEED RATE = 4500 LBS/24 HOURS)

	Unit 1	Unit 2	Unit 3	Unit 4
Average Free Residual Chlorine Consumed	2.15	2.36	2.30	2.43
Average Total Residual Chlorine Consumed	1.48	1.57	1.64	1.72

2. Fixed Duration of Feed

Effects within units were used to make inferences about the response of chlorine consumption to varying the feed rate and different inlet water temperatures. Each unit had a different duration of feed, so the sources of variation affecting chlorine consumption for a given unit were feed rate, time, inlet water temperature, and chlorine demand. Chlorine demand can be assumed equal for all units. The mean free residual chlorine consumed in the system for each feed rate, time interval, and unit is presented in Table A-5.

With respect to the free residual chlorine consumption for fixed duration of feed, there was a consistent trend for consumption to decline as the feed rate declined. Free residual chlorine consumption tended to increase as inlet water temperature increased. The FRC consumption declined to about 1.02 mg/l for inlet water temperatures of 60°F or less.

Reliable data for total residual chlorine consumed in the system was available for May, June, and July at a feed rate of 4500 lbs/24 hours. Table A-6 displays the mean total residual chlorine consumed by data for the different units.

TABLE A-5

MEANS OF FREE RESIDUAL CHLORINE CONSUMED IN SYSTEM
IN mg/l (SAMPLE SIZE)

Feed Rate (lbs/24 hours)	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	May	2.12(3)	2.67(1)	2.41(4)	2.45(3)
	June	2.17(4)	2.33(5)	2.29(5)	2.41(5)
	July	2.13(2)	2.28(2)	1.94(1)	2.44(2)
2500	Sept.	1.26(2)	1.18(2)	1.33(2)	1.37(2)
1500	Oct/Nov	1.04(2)	0.98(2)	1.05(2)	1.03(2)

TABLE A-6

MEANS OF TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM
IN mg/l (SAMPLE SIZE) FEED RATE = 4500 LBS/24 HOURS

Date	Unit 1	Unit 2	Unit 3	Unit 4
May	1.41(2)	1.48(1)	1.95(2)	1.68(3)
June	1.44(4)	1.60(5)	1.54(5)	1.72(5)
July	1.63(2)	1.56(2)	1.51(1)	1.82(2)

3. Varying Feed Rate, Frequency, and Duration of Feed

Free residual chlorine consumed in the system is, as expected, most responsive to feed rate. As the feed rate is lowered, consumption is lowered. Table A-7 presents the analysis of variance table (ANOVA) for the free residual chlorine consumption over all feed rates.

Table A-7

FREE RESIDUAL CHLORINE CONSUMED IN SYSTEM
ALL FEED RATES

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Feed Rate	2	15.1487	7.5744	105.66	.001
Units	3	0.0766	0.0255	0.36	>.25
Interaction	6	0.1517	0.0253	0.35	>.25
Error	41	2.9391	0.0717		
Total	52	18.6273			

The effect of frequency and duration of feed as identified by the "unit factor" was not significant. A test for interaction effects yielded no significant interaction indicating that a single variable model was essentially correct for free residual chlorine consumption.

Total residual chlorine consumption in the system may have had a marginal effect due to "unit factor." The statistical evidence for this effect is weak since the significance level is only 0.12. Table A-8 shows the analysis of variance table for the analysis. Available data did not allow quantitative analysis of varying feed rates.

Table A-8

TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM
FEED RATE = 4500 LBS/24 HOURS

ANOVA

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Time	2	0.0397	0.0199	.43	>.25
Units	3	0.2929	0.0976	2.10	0.12 approx.
Error	28	1.3023	0.0465		
Total	33	1.6361			

4. Statistical Analysis

a. ANOVA Table for Free Residual Chlorine Consumed in System with a Feed Rate of 4500 Lbs/24 Hours

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Time	2	0.0970	0.0485	0.57	>.25
Units	3	0.4307	0.1436	1.68	>.15
Error	31	2.6487	0.0854		
Total	36	3.1552			

Conclude time and units are not significant at the .10 level.

C. Phase III--System Consumption of Free Residual Chlorine

1. Constant Feed Rate

The Phase III data did not contain an adequate number of data points for a fixed feed rate and duration of feed to evaluate FRC consumption with regard to time, inlet water temperature, or water quality parameters.

2. Varying Feed Rates and Durations of Feed

An unbalanced analysis of variance (ANOVA) was conducted to examine the system consumption of FRC as a function of feed rate, frequency and duration of feed identified as "block," and inlet water temperature as a covariate. As Table A-9 indicates, feed rate and block were significant factors. Table A-10 shows the feed, block, and individual cell means which indicate that a feed rate of 3500 lbs/24 hours and block 1 (a frequency of two times/day for 30 minute durations) had a slightly higher FRC consumption than the remainder of the feed and block combinations. No factor could be identified as the cause of the high FRC consumptions for the two data points available.

Table A-9

FRC CONSUMED IN SYSTEM
UNBALANCED ANOVA OF CHLORINE DATA

DEPENDENT VARIABLE: FRC-CON

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	R-SQUARE
MODEL	12	0.82772190	0.06897682	5.68	0.872029
ERROR	10	0.12146941	0.01214694	PR > F	
CORRECTED TOTAL	22	0.94919130		0.0049	

SOURCE	DF	TYPE I SS	F VALUE	PR > F
FEED	2	0.62361988	25.67	0.0001
BLOCK	3	0.15952737	4.38	0.0326
IWT	1	0.00060224	0.05	0.8283
BLOCK*FEED	6	0.04397241	0.60	0.7230
	DF	TYPE IV SS	F VALUE	PR > F
	2	0.14045049	5.78	0.0215
	3	0.13600001	3.73	0.0492
	1	0.00125059	0.10	0.7549
	6	0.04397241	0.60	0.7230

In general, by adjusting the feed rate as a function of inlet water temperature as was done in Phase III, it would be expected that the system consumption of FRC would be fairly constant. However, the model significance level of 0.01 in Table A-11 shows that variations in FRC consumption are probably not random fluctuations around a constant value. The chlorination scheme is designed to meet the water and system demand and provide enough FRC to maintain adequate condenser performance. Table A-11 presents the ANOVA for the significant factors affecting FRC consumption with inlet water temperature as a covariate, which is not significant.

Table A-10

MEAN FREE RESIDUAL CHLORINE SYSTEM CONSUMPTION

FEED	N	MEAN FRC CONSUMED
2500	9	1.35666667
3000	7	1.47428571
3500	7	1.75000000

BLOCK*	N	MEAN FRC CONSUMED
1	5	1.69400000
2	9	1.41666667
3	4	1.55750000
4	5	1.46600000

BLOCK	FEED	N	MEAN FRC CONSUMED
1	2500	1	1.46000000
1	3000	2	1.60000000
1	3500	2	1.90500000
2	2500	5	1.29400000
2	3000	2	1.42000000
2	3500	2	1.72000000
3	2500	1	1.55000000
3	3000	2	1.47500000
3	3500	1	1.73000000
4	2500	2	1.36500000
4	3000	1	1.33000000
4	3500	2	1.63500000

---

*Block 1 is chlorinating 2 times/day for 30 minutes.
Block 2 is chlorinating 3 times/day for 20 minutes.
Block 3 is chlorinating 6 times/day for 10 minutes.
Block 4 is chlorinating 2 times/day for 60 minutes.

3. Possible Relationship to Water Quality Parameters

FRC consumption in the system was examined for possible relationships with ammonia, organic nitrogen, Kjeldahl nitrogen, nitrates plus nitrites, pH, conductivity, alkalinity, total suspended solids, and total organic carbon. Although feed and block explained a significant portion of the variation, analysis indicated that organic nitrogen and pH were additional factors affecting FRC consumption. However, the organic nitrogen and pH are correlated with each other (simple correlation coefficient of 0.68). Of the two, organic nitrogen was the more dominant, as can be seen by the ANOVA analyses summarized in Tables A-12 and A-13.

Table A-11

FRC CONSUMED IN SYSTEM
UNBALANCED ANOVA OF CHLORINE DATA

```
DEPENDENT VARIABLE:  FRC-CON
SOURCE                   DF    SUM OF SQUARES    MEAN SQUARE    F VALUE    R-SQUARE
MODEL                     6      0.78374949       0.13062491      12.63     0.825702
ERROR                    16      0.16544182       0.01034011
CORRECTED TOTAL          22      0.94919130                      PR > F
                                                                 0.0001

SOURCE                   DF       TYPE I SS       F VALUE        PR > F

FEED                      2      0.62361988        30.16         0.0001
BLOCK                     3      0.15952737         5.14         0.0111
IWT                       1      0.00060224         0.06         0.8124


                         DF      TYPE IV SS       F VALUE        PR > F

                          2      0.16181190         7.82         0.0043
                          3      0.15701810         5.06         0.0118
                          1      0.00060224         0.06         0.8124
```

Table A-12

FRC CONSUMED IN SYSTEM

```
DEPENDENT VARIABLE:  FRC-CON
SOURCE                   DF    SUM OF SQUARES    MEAN SQUARE    F VALUE    R-SQUARE
MODEL                     7      0.83326729       0.11903818      15.40     0.877871
ERROR                    15      0.11592402       0.00772827     PR > F
CORRECTED TOTAL          22      0.94919130                      0.0001

SOURCE                   DF       TYPE I SS       F VALUE        PR > F

FEED                      2      0.62361988        40.35         0.0001
BLOCK                     3      0.15952737         6.88         0.0039
ORGN                      1      0.04241764         5.49         0.0333
pH                        1      0.00770240         1.00         0.3340

                         DF      TYPE IV SS       F VALUE        PR > F

                          2      0.54177162        35.05         0.0001
                          3      0.10069917         4.34         0.0216
                          1      0.01333816         1.73         0.2087
                          1      0.00770240         1.00         0.3340
```

Table A-13

FRC CONSUMED IN SYSTEM

```
DEPENDENT VARIABLE:  FRC-CON
SOURCE                    DF    SUM OF SQUARES     MEAN SQUARE     F VALUE     R-SQUARE
MODEL                      6        0.81992912      0.13665485       16.92     0.863819
ERROR                     16        0.12926218      0.00807889     PR > F
CORRECTED TOTAL           22        0.94919130                      0.0001

SOURCE                    DF         TYPE I SS         F VALUE      PR > F

FEED                       2        0.62361988           38.60      0.0001
BLOCK                      3        0.15952737            6.58      0.0042
pH                         1        0.03678188            4.55      0.0487


                          DF        TYPE IV SS         F VALUE      PR > F

                           2        0.53016627           32.81      0.0001
                           3        0.13242017            5.46      0.0089
                           1        0.03678188            4.55      0.0487
```

D. Phase III--System Consumption of Total Residual Chlorine

1. Constant Feed Rate

The Phase III data did not contain an adequate number of data points for a fixed feed rate and duration of feed to evaluate TRC consumption with regard to time, inlet water temperature, or water quality parameters.

2. Varying Feed Rates and Duration of Feed

The system consumption of TRC was examined as a function of feed rate, frequency and duration of feed labeled as "block," with inlet water temperature as a covariate. As Table A-14 indicates, feed rate was the most influential with block and inlet water temperature. Since no feed and block interaction is apparent in Table A-15, a simple additive model describes the data. Table A-16 lists the average TRC consumption by feed rate, by frequency and duration combinations (blocks), and for the feed rate and block cells. Significantly low TRC consumptions occurred at a feed rate of 2500 lb/24 hours.

Table A-14

TRC CONSUMED IN SYSTEM

UNBALANCED ANOVA

```
DEPENDENT VARIABLE:  TRC-CON
SOURCE                    DF    SUM OF SQUARES    MEAN SQUARE     F VALUE     R-SQUARE
MODEL                      6      0.49936128       0.08322688       14.98     0.848902
ERROR                     16      0.08888220       0.00555514      PR > F
CORRECTED TOTAL           22      0.58824348                       0.0001


SOURCE                    DF       TYPE I SS        F VALUE        PR > F

FEED                       2      0.44212919         39.79         0.0001
BLOCK                      3      0.04561002          2.74         0.0778
IWT                        1      0.01162206          2.09         0.1674


                          DF      TYPE IV SS        F VALUE        PR > F

                           2      0.24459647         22.02         0.0001
                           3      0.04039404          2.42         0.1036
                           1      0.01162206          2.09         0.1674
```

Table A-15

TRC CONSUMED IN SYSTEM

UNBALANCED ANOVA

```
DEPENDENT VARIABLE:  TRC-CON
SOURCE                     DF     SUM OF SQUARES      MEAN SQUARE     F VALUE     R-SQUARE
MODEL                      12         0.52351223       0.04362602        6.74     0.889958
ERROR                      10         0.06473124       0.00647312      PR > F
CORRECTED TOTAL            22         0.58824348                       0.0025


SOURCE                     DF        TYPE I SS          F VALUE        PR > F

FEED                        2         0.44212919          34.15        0.0001
BLOCK                       3         0.04561002           2.35        0.1341
IWT                         1         0.01162206           1.80        0.2099
BLOCK*FEED                  6         0.02415096           0.62        0.7101


                           DF       TYPE IV SS          F VALUE        PR > F

                            2         0.20003791          15.45        0.0009
                            3         0.03607036           1.86        0.2007
                            1         0.00498876           0.77        0.4880
                            6         0.02415096           0.62        0.7101
```

Table A-16

MEAN TOTAL RESIDUAL CHLORINE SYSTEM CONSUMPTION

		MEANS
FEED	N	TRC-CON
2500	9	0.83000000
3000	7	1.10285714
3500	7	1.12428571

BLOCK	N	TRC-CON
1	5	1.12400000
2	9	0.93777778
3	4	1.06500000
4	5	0.94800000

BLOCK	FEED	N	TRC-CON
1	2500	1	0.84000000
1	3000	2	1.21000000
1	3500	2	1.18000000
2	2500	5	0.81400000
2	3000	2	1.02500000
2	3500	2	1.16000000
3	2500	1	0.91000000
3	3000	2	1.12500000
3	3500	1	1.10000000
4	2500	2	0.82500000
4	3000	1	1.00000000
4	3500	2	1.04500000

3. Possible Relationship to Water Quality Parameters

TRC system consumption was examined for possible relationships with various water quality parameters. Analysis indicated total suspended solids were correlated with TRC system consumption (simple correlation coefficient of 0.45) as was 5-minute chlorine demand (simple correlation coefficient of 0.83). In examining the intercorrelation between the various water quality parameters, it became apparent that several water quality parameters might be contributing to the system consumption of TRC. Examination of several regression models indicates that, based on Phase III data, total suspended solids and 5-minute chlorine demand were the water quality parameters most affecting system TRC consumption. The following equation was the best estimate using regression analyses:

$$\text{TRC-CON} = .3901 + .0061\ \text{TSS} + .8855\ \text{D5}$$

where TRC-CON is the amount of TRC consumed in the system, TSS is the total suspended solids, and D5 is the 5-minute chlorine demand. The above model explains 72 percent of the total variation in system TRC consumption. The F statistic for the model is 53.17 and is highly significant. The error mean square was .0032. the sample size was 42.

E. Condenser-Related Free and Total Residual Chlorine Behavior

1. Free Residual Chlorine at the Condenser Inlet

The amount of free residual chlorine (FRC) at the condenser inlet for a fixed feed rate, frequency, and duration is different over time. The reason for the difference is inlet water temperature. The following model was fit to Phase III data for a fixed feed rate of 2500 lbs/24 hours and frequency of feed of 3 times/day for 20 minutes. For this combination, there were eight data points available.

$$\text{FREE-IN} = 9.9226 - 0.1186\ \text{IWT}$$

where FREE-IN is the amount of FRC at the condenser inlet, and IWT is the inlet water temperature. The above model explained 69 percent of the total variation in the FRC at the condenser inlet.

The amount of FRC at the condenser inlet does vary with the feed rate, and with the frequency and duration of feed. Tables A-17 and A-18, respectively, give the ANOVA and the mean FRC at the condenser inlet. Table A-17 indicates that feed is highly significant with the block (frequency and duration of feed) effect being moderately significant. Table A-18 indicates that the amount of FRC at the condenser inlet increased with feed rate and was the highest at 3500 lbs/24 hours at 0.62 mg/l. Block 2, which is feeding three times/day for 20 minutes duration, had the highest FRC at the inlet, 0.41 mg/l. While the Phase III data in Table A-17 did not show inlet water temperature as being a significant factor after considering the effects of feed rate and block, it is felt that inlet water temperature is a significant factor as the fixed data indicated.

An analysis was carried out to determine if any of the water quality parameters had an effect on the FRC measured at the condenser inlet. Correlation analysis indicated a number of factors might be related to the FRC at the inlet. Table A-19 lists the factors and their simple correlation coefficient.

Table A-17

UNBALANCED ANOVA OF FREE RESIDUAL CHLORINE AT THE CONDENSER INLET

```
DEPENDENT VARIABLE:  FREE-IN
SOURCE                    DF    SUM OF SQUARES      MEAN SQUARE      F VALUE      R-SQUARE
MODEL                     12      0.86931519        0.07244293          2.51      0.715258
ERROR                     12      0.34608481        0.02984040        PR > F
CORRECTED TOTAL           24      1.21540880                          0.0622


SOURCE                    DF       TYPE I SS          F VALUE         PR > F

FEED                       2      0.63395065           10.99          0.0019
BLOCK                      3      0.15769490            1.82          0.1967
IWT                        1      0.00006920            0.00          0.9617
FEED*BLOCK                 6      0.07760044            0.45          0.8328


                          DF      TYPE IV SS          F VALUE         PR > F

                           2      0.24006886            4.16          0.0424
                           3      0.11151803            1.29          0.3229
                           1      0.00000090            0.00          0.9956
                           6      0.07760044            0.45          0.8328
```

Table A-18

MEAN FREE RESIDUAL CHLORINE AT CONDENSER INLET

FEED	N	MEANS FREE-IN
2500	11	0.25181818
3000	7	0.29142857
3500	7	0.62000000

BLOCK*	N	FREE-IN
1	5	0.31200000
2	11	0.40545455
3	4	0.33000000
4	5	0.36200000

FEED	BLOCK	N	FREE-IN
2500	1	1	0.15000000
2500	2	7	0.31857143
2500	3	1	0.10000000
2500	4	2	0.14500000
3000	1	2	0.24000000
3000	2	2	0.30500000
3000	3	2	0.27500000
3000	4	1	0.40000000
3500	1	2	0.46500000
3500	2	2	0.81000000
3500	3	1	0.67000000
3500	4	2	0.56000000

*Block 1 is chlorinating 2 times/day for 30 minutes
Block 2 is chlorinating 3 times/day for 20 minutes
Block 3 is chlorinating 6 times/day for 10 minutes
Block 4 is chlorinating 2 times/day for 60 minutes

Table A-19

FACTORS CORRELATED* WITH FRC AT THE CONDENSER INLET

Factor	Simple Correlation Coefficient
Chlorine Dosage at Intake	0.57
10-Minute Demand	0.41
Conductivity	-0.41
Organic Nitrogen	-0.49
pH	-0.34
Total Nitrates-Nitrites	0.37
Kjeldahl Nitrogen	-0.32

*Significance level of .05 or smaller

The correlation analysis indicated the possibility of water quality parameters contributing to the variation of FRC at the condenser inlet. The following model, estimated using regression analysis, indicates that the amount of FRC at the inlet is a result of the chlorine dosage at the intake and is dependent upon the organic nitrogen content of the water, the conductivity, and the inlet water temperature,

$$\text{FREE-IN} = .8531 - .0011\ \text{COND} - 1.1202\ \text{ORGN} + .3539\ Cl_2 - .0077\ \text{IWT}$$

where COND is the conductivity, ORGN is the organic nitrogen, Cl_2 if the chlorine dosage at the intake, and IWT is the inlet water temperature. The above model explains 64 percent of the total variation of the inlet FRC and has an F-statistic of 16.76, which is highly significant. The error mean square is 0.0161. This model is based on verified phase III data.

To further examine the behavior of FRC at the condenser inlet and perhaps gain a better understanding of the chlorination chemistry, the amount of FRC at the condenser inlet was examined as a fraction of the total residual chlorine (TRC) at the condenser inlet. Table A-20 summarizes the correlation analysis of factors possibly related to the fraction of TRC at the condenser inlet which is FRC.

Table A-20

FACTORS CORRELATED* WITH THE FRACTION OF FRC/TRC AT THE CONDENSER INLET

Factor	Simple Correlation Coefficient
pH	-0.30
Conductivity	-0.47
Organic Nitrogen	-0.41
Total Nitrates-Nitrites	0.39

*Significant level of .05 or smaller.

The fraction of TRC at the condenser inlet exhibited some of the same correlative factors as the FRC at the condenser inlet. The best model explaining the variation in the fraction was surprising. It is

$$PCT = 2.4513 - .0010\ COND - .1273\ pH - 1.4124\ ORGN - .0064\ IWT$$

where PCT is the predicted fraction of the TRC at the condenser inlet which is FRC, COND is the conductivity, ORGN is the organic nitrogen in the water, and IWT is the inlet water temperature. The above model explains 45 percent of the variation. In comparing this model with the one derived for FRC, conductivity, organic nitrogen, and inlet water temperature were the common factors. This suggested that the water quality parameters might be intercorrelated, which they are (see the section on Interrelationships Between Water Quality Parameters).

Taking both approaches into account then suggests that the amount of FRC at the condenser inlet is related to chlorine dosage, inlet water temperature, and water quality parameters. Of the water quality parameters, conductivity stands out along with the organic nitrogen compounds in the water.

2. Condenser Consumption of Chlorine

Analysis focused on the amount of FRC consumed in the condenser. Correlation analysis indicated that inlet water temperature ($r = -0.34$) and the one-minute chlorine demand ($r = -0.33$) were possible factors having a significant effect on condenser consumption of FRC. The following model explained 62 percent of the total variation of FRC consumed in the condenser:

$$DELTA\text{-}F = -.3195 + .4340\ FREE\ IN + .0041\ ALK - .1530\ D5$$

where DELTA-F is the amount of FRC consumed in the condenser, FREE IN is the FRC at the condenser inlet, ALK is the alkalinity, and D5 is the five-minute chlorine demand. The F-statistic is 21.46, which is highly significant. The error mean square is .0046.

IV. DESCRIPTIVE STATISTICS

Descriptive statistics related to chlorine consumption of the condenser are presented below.

A. Phase II

1. Mean Free Residual Chlorine at Inlet of Condenser (Sample Size)

(a) By unit

Unit 1 = 0.52(14)
Unit 2 = 0.43(14)
Unit 3 = 0.46(13)
Unit 4 = 0.43(13)

(b) By feed rate

4500:	0.61(26)
2500:	0.42(14)
1500:	0.23(14)

(c) Overall mean = 0.46(54)

2. Mean Free Residual Chlorine at Outlet of Condenser (Sample Size)

(a) By unit Unit 1 = 0.43(14) Unit 3 = 0.38(14)
Unit 2 = 0.36(14) Unit 4 = 0.33(14)

(b) By feed rate 4500: 0.48(28)
2500: 0.34(14)
1500: 0.20(14)

(c) Overall mean = 0.38(56)

3. Mean Free Residual Chlorine Consumed in Condenser (sample size)

(a) By unit Unit 1 = 0.09(14) Unit 3 = 0.08(13)
Unit 2 = 0.08(14) Unit 4 = 0.10(13)

(b) By feed rate 4500: 0.13(26)
2500: 0.07(14)
1500: 0.03(14)

(c) Overall mean = 0.09(54)

4. Mean Total Residual Chlorine at Inlet of Condenser (sample size)

(a) By unit Unit 1 = 1.09(12) Unit 3 = 1.08(12)
Unit 2 = 1.07(11) Unit 4 = 1.06(12)

(b) By feed rate 4500: 1.22(24)
2500: 0.96(13)
1500: 0.70(10)

(c) Overall mean = 1.08(47)

5. Mean Total Residual Chlorine at Outlet of Condenser (Sample Size)

(a) By unit Unit 1 = 1.05(12) Unit 3 = 1.05(12)
Unit 2 = 1.05(11) Unit 4 = 1.01(12)

(b) By feed rate 4500: 1.22(24)
2500: 0.91(13)
1500: 0.67(10)

(c) Overall mean = 1.04(47)

6. Mean Total Residual Chlorine Consumed in Condenser (Sample Size)

(a) By unit Unit 1 = 0.05(12) Unit 3 = 0.03(12)
Unit 2 = 0.01(11) Unit 4 = 0.06(12)

(b) By feed rate 4500: 0.04(24)
2500: 0.05(13)
1500: 0.03(10)

(c) Overall mean = 0.04(47)

B. Phase III

1. Condenser Chlorine Consumption-Related Statistics

a. Mean Free and Total Residual Chlorine at Inlet of Condenser in mg/l (Sample Size)

(1) By feed rate in lbs/24 hours

	Free Residual Chlorine (FRC)		Total Residual Chlorine (TRC)	
1500	0.24	(2)	0.51	(2)
2500	0.25	(11)	0.73	(10)
3000	0.29	(7)	0.83	(7)
3500	0.62	(7)	1.13	(8)

(2) By block*

	FRC	TRC
1	0.31 (5)	0.90 (5)
2	0.41 (11)	0.85 (10)
3	0.30 (5)	0.89 (6)
4	0.35 (6)	0.81 (6)

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*Each block is a particular frequency and duration of feed combination
where block 1 = chlorine feed 2 times/day, 30 minutes each time
block 2 = chlorine feed 3 times/day, 20 minutes each time
block 3 = chlorine feed 6 times/day, 10 minutes each time
block 4 = chlorine feed 2 times/day, 60 minutes each time

(3) Overall mean

FRC	TRC
0.36 (27)	0.86 (27)

b. Mean Free and Total Residual Chlorine at Outlet of Condenser in mg/l (Sample Size)

(1) By feed rate in lbs/24 hours

	FRC	TRC
1500	0.07 (2)	0.46 (2)
2500	0.22 (11)	0.71 (10)
3000	0.42 (7)	0.79 (7)
3500	0.41 (8)	1.20 (8)

(2) By block

	FRC	TRC
1	0.28 (5)	0.85 (5)
2	0.34 (11)	0.80 (10)
3	0.32 (6)	1.04 (6)
4	0.28 (6)	0.78 (6)

(3) Overall mean

FRC	TRC
0.31 (28)	0.86 (27)

c. Mean Free and Total Residual Chlorine Consumed in Condenser (Sample Size)

(1) By feed rate

	FRC Consumed	TRC Consumed
1500	0.18 (2)	0.05 (2)
2500	0.04 (11)	0.02 (10)
3000	-0.13 (7)	0.04 (7)
3500	0.19 (7)	-0.07 (8)

(2) By block

	FRC	TRC
1	0.03 (5)	0.05 (5)
2	0.07 (11)	0.05 (10)
3	-0.03 (5)	-0.15 (6)
4	0.07 (6)	0.04 (6)

(3) Overall mean	FRC Consumed	TRC Consumed
	0.04 (27)	0.001 (27)

C. Average Condenser Consumption of FRC and TRC

Average condenser consumption of free residual chlorine for Phase III was 0.04 mg/l with an average FRC of 0.36 mg/l at the inlet and 0.31 mg/l at the condenser outlet. When compared with the Phase II figures of 0.46 mg/l at the inlet, 0.38 mg/l at the condenser outlet and an average of 0.08 mg/l of FRC consumption in the condenser, it becomes apparent that the outlet FRC was reduced because of the inlet FRC reduction. The average condenser demand in Phase III was approximately half of that in Phase II, which confirms the trend noted in Phase II of the condenser consumption declining as the feed rate declined. The average condenser consumption of FRC is depressed by some large negative consumption figures. If these figures are left out of the analysis, then the overall average consumption of FRC in the condenser is about 0.10 mg/l. This figure is still smaller than previous estimates of average condenser demand (0.3-0.5 mg/l) and is probably due in part to the reduced feed rate used in Phase III.

Average condenser consumption of total residual chlorine for Phase III was 0.001 mg/l with an average TRC of 0.86 mg/l at the inlet and 0.86 mg/l at the outlet. The figures for Phase II were a TRC average consumption of 0.04 mg/l with 1.08 mg/l at the inlet and 1.04 mg/l at the outlet. Again, the effects of reducing the overall feed rate are seen.

D. Negative Condenser Consumption

Eighteen instances of negative FRC consumption greater than 0.05 mg/l across the condenser occurred during the Phase III. They occurred on twelve different dates and at least once on each unit. The values for chlorine dosage, inlet FRC, and outlet FRC do not systematically deviate from the means for these variables. Since there appeared to be some relationship between conductivity and alkalinity and negative FRC consumption, FRC was modeled as a function of those parameters. Conductivity was consistently significant in the model; however, alkalinity was not highly significant.

The regression model confirmed the trend that was seen in the raw data--an increase in conductivity is associated with a decrease in FRC consumption across the condenser. However, the model had such a poor r^2 value (predicted FRC consumptions less negative than those observed in the data) that we have not included it in this report. Two data points were excluded from consideration in the model and the calculation of means; although they are listed in the data tables. FRC consumption for Unit 3 on May 9, 1978, was deleted because of the unusually high inlet FRC measurement and the TRC consumption for May 16, 1978, was deleted because of the high outlet TRC measurement. The following table summarizes the data:

Table A-21

DATA ASSOCIATED WITH LARGE NEGATIVE CONDENSER CONSUMPTION OF FREE RESIDUAL CHLORINE

Date	Unit	FRC at Inlet	FRC at Outlet	Condenser Consumption	Cond.	Alka.
7-7-78	4	0.150	0.520	-0.370	430	94
7-7-78	2	0.150	0.480	-0.330	430	94
5-9-78	2	0.060	0.320	-0.260	350	90
7-7-78	3	0.160	0.390	-0.230	430	94
10-31-78	1	0.360	0.570	-0.210	400	90
11-14-78	1	0.210	0.420	-0.210	-	-
5-9-78	4	0.040	0.222	-0.182	350	90
10-31-78	3	0.390	0.560	-0.170	400	90
10-31-78	2	0.400	0.490	-0.090	400	90
10-28-77	1	0.211	0.297	-0.086	240	78
11-18-77	3	0.068	0.150	-0.082	220	80
5-5-78	3	0.030	0.110	-0.080	290	86
5-4-78	3	0.070	0.140	-0.070	-	-
11-28-78	2	0.360	0.420	-0.060	410	90
6-20-78	4	0.410	0.470	-0.060	-	-
10-31-78	4	0.420	0.480	-0.060	400	90
11-28-78	4	0.420	0.480	-0.060	410	90
11-18-77	4	0.087	0.145	-0.058	220	80

Phase III Averages: COND = 308.8 µmhos
ALKA = 85.0 mg/l

Ten instances of negative TRC consumption greater than 0.05 mg/l, across the condenser occurred during Phase III. These occurred on eight different dates, three of which corresponded with the dates which had negative FRC consumption. Of the ten instances of negative TRC consumption only three occurred on the same date, November 18, 1977. The data are presented below.

Table A-22

DATA ASSOCIATED WITH LARGE NEGATIVE CONDENSER CONSUMPTION OF TOTAL RESIDUAL CHLORINE

		TRC at		Condenser		
Date	Unit	Inlet	Outlet	Consumption	Cond.	Alka.
5-16-78	4	1.160	2.200	-1.040	340	91
5-23-78	3	1.000	1.270	-0.270	340	83
5-9-78	2	1.040	1.210	-0.170	350	90
4-13-78	4	0.400	0.550	-0.150	360	100
2-17-78	4	0.430	0.550	-0.120	290	89
7-18-78	2	0.650	0.720	-0.070	320	91
11-18-77	3	0.550	0.617	-0.067	220	80
11-18-77	4	0.548	0.613	-0.065	220	80
5-5-78	3	1.160	1.220	-0.060	290	86
11-18-77	2	0.451	0.504	-0.053	220	80

No model was found which described TRC consumption as a function of water quality parameters.

E. Condenser Outlet Compared With Point of Compliance

Tests were conducted on November 2, November 6, and November 9, 1978, for Units 2, 3, and 4 to compare free and total residual chlorine readings at the outlet of the condenser and the point of compliance. All three units were feeding 2500 lbs/24 hours (a higher feed rate than recommended), three times per day, for 20 minutes duration. Table A-23 below compares the estimated steady-state maximum free residual chlorine on all three dates for all three units.

Table A-23

MAXIMUM STEADY-STATE FREE RESIDUAL CHLORINE READING (mg/l)

Date	Unit	Condenser Outlet	Point of Compliance	Difference
11-2-78	2	0.50	0.15	0.35
	3	0.30	0.20	0.10
	4	0.35	0.20	0.15
11-6-78	2	0.15	0.14	0.01
	3	0.15	0.15	0.00
	4	0.15	0.10	0.05
11-9-78	2	0.40	0.30	0.10
	3	0.15	0.10	0.05
	4	0.15	0.10	0.10
Overall Average		0.26	0.16	0.10
Unit 2 Average		0.35	0.20	0.15
Unit 3 Average		0.20	0.15	0.05
Unit 4 Average		0.22	0.13	0.10

On the average, the difference between the condenser outlet and the point of compliance was approximately 0.10 mg/l of free residual chlorine while averaging 0.16 mg/l at the point of compliance. The high reading of 0.26 mg/l at the condenser outlet results from the feed rate of 2500 lbs/24 hours while the associated inlet water temperature on these dates was in the low 60°'s F. The free residual chlorine reading at the point of compliance can be hypothesized as being a function of the free residual chlorine at the condenser outlet, diminished by the demand of the water, plus the time effect resulting from a flow rate. However, insufficient data at the time does not allow the identification or estimation of the above effects.

Unit 2 indicated a higher free residual chlorine reading on the average than did Units 3 and 4. The average higher reading was consistant at the point of compliance also. There was no identifiable reason for the higher readings of Unit 2.

Table A-24 compares the estimated steady-state maximum for total residual chlorine on all three dates for all three units.

Table A-24

MAXIMUM STEADY-STATE TOTAL RESIDUAL CHLORINE READING (mg/l)

Date	Unit	Condenser Outlet	Point of Compliance	Difference
11-2-78	2	0.90	0.70	0.20
	3	0.85	0.72	0.13
	4	0.85	0.72	0.13
11-6-78	2	0.80	0.70	0.10
	3	0.80	0.70	0.10
	4	0.75	0.74	0.01
11-9-78	2	1.15	0.84	0.31
	3	0.80	0.70	0.10
	4	0.72	0.68	0.04
Overall Average		0.85	0.72	0.12
Unit 2 Average		0.95	0.75	0.20
Unit 3 Average		0.82	0.71	0.11
Unit 4 Average		0.77	0.71	0.06

On the average, the difference in total residual chlorine readings between the condenser outlet and point of compliance was 0.12 mg/l with an average total residual chlorine reading of 0.72 mg/l at the point of compliance. Unit 2 had higher readings of total residual chlorine at the condenser outlet and at the point of compliance, as occurred in the free residual chlorine readings. The higher chlorine readings of Unit 2 are apparently real. No present explanation can be made which can be based on the data.

Table A-25 presents the ratio of the free residual chlorine reading to the total residual chlorine for all three units for all three dates.

This ratio is a rough indicator of the transition of free residual chlorine into combined forms of chlorine. It appears that Unit 2 at the condenser outlet had more free residual chlorine available for transformation into combined compounds than did the other units. This would indicate that the feed rate to Unit 2 could be reduced until the free residual chlorine readings at the condenser outlet are closer to those of Units 3 and 4. A possible malfunction in the automatic chlorine feed system may be attributing to this phenomenon on Unit 2. The automatic valves on Unit 2 may not be closing off when the other units are being chlorinated.

Table A-25

RATIO OF STEADY-STATE MAXIMUM FREE RESIDUAL CHLORINE READING TO MAXIMUM TOTAL RESIDUAL CHLORINE READING

Date	Unit	Condenser Outlet	Point of Compliance
11-2-78	2	0.56	0.21
	3	0.35	0.28
	4	0.41	0.28
11-6-78	2	0.19	0.20
	3	0.19	0.21
	4	0.20	0.14
11-9-78	2	0.35	0.36
	3	0.19	0.14
	4	0.21	0.15
Overall Ratio		0.31	0.22
Unit 2 Ratio		0.37	0.27
Unit 3 Ratio		0.24	0.21
Unit 4 Ratio		0.29	0.18

F. Interrationships Between Water Quality Parameters

This section summarizes an analysis performed to identify the water quality parameters in Phase III which correlated with each other. This section was the result of observing that different water quality parameters were related to chlorine consumption and also related to each other. The following table of correlation coefficients is self-explanatory:

Table A-26

INTERRELATIONSHIPS BETWEEN WATER QUALITY PARAMETERS

	COND	ALKA	TSS	TOC	NH_3	ORGN	$NH_2 + NH_3$	KJN
pH	.03	.20	-.18	.06	-.34*	.09	-.21	-.21
COND		.53*	.02	.01	.33*	.33*	-.38*	.38*
ALKA			.05	-.01	.39*	.02	-.29	.29
TSS				.20	-.29	-.54*	-.20	-.45*
TOC					-.01	.13	-.40*	.05
NH_3						.45*	.13	.92*
ORGN							-.27	.76*
$NH_2 + NH_3$								-.03

*Significance level .05 or smaller.

These variables, which are highly correlated with each other, are identified with an asterisk by the simple correlation coefficient.

Probability > /R/, under H_o: $RH_o = 0$, is < .05

Note: High correlation does not necessarily imply a causal relationship.

APPENDIX B

DATA FOR ANALYSIS

		Inlet Free			Outlet Free			Difference* Steady State Free Inlet-Outlet	Inlet Total			Outlet Total			Difference* Steady State Total Inlet-Outlet
Date	Unit	Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used		Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	
5/06/77	1	.417	.410	.1;.8	.356	.351	.25;.49	.059	1.33	1.52	.2;.6	1.24	1.31	.55;1.4	.21
5/06/77	2	.797	.734	.15;1.88		No Data		-	1.53	1.62	.29;2.2		No Data		-
5/06/77	3	.56	.483	.35;1.0	.482	.523	.15;.69	-.041	1.46	1.48	1.3;1.6	1.41	1.40	1.37;1.45	.08
5/12/77	1	1.15	1.26	.1;.3		No Data		-	1.43	1.49	.1;.4;.9; 9;.92		No Data		-
5/12/77	3	1.40	1.60	.3;.66;1.68	.242	.233	.12;.44	1.37	1.42	1.60	.3;.66;1.8	.79	.77	.29;.3;1.87	.83
5/12/77	4	.797	.936	.1	.375	.355	.17;.66	.58	.797	.936	.1	.91	.917	.17;1.62	.019
5/20/77	1	1.13	1.135	.4;1.3	.868	.864	.78;.91	.271	1.53	1.57	.5;1.75	1.15	1.19	.39;1.36	.38
5/20/77	3	.98	1.2	.1;.3	.877	1.0	.61;1.02	.20	1.21	1.44	.1;1.8	1.54	1.54	-	-.10
5/20/77	4	.7	1.15	.1	.577	.7	.33	.45	1.07	1.4	.2;.3	1.1	1.22	.88	.18
5/27/77	1	.512	.496	.1;.8	.223	.234	.08;.32	.262	1.26	1.3	.3;1.45	1.28	1.38	.08;1.46	-.08
5/27/77	2	.478	.414	.22;1.5	.234	.236	.2;.26	.178	1.28	1.41	.4	1.43	1.43	.52;1.48	-.12
5/27/77	3	.345	.375	.1;.5	.206	.208	.14;.26	.167	1.10	1.15	.2;1.55	1.32	1.43	.52;1.48	-.28
5/27/77	4	.367	.467	.1;.6	.22	.22	-	.247	.87	1.51	.1;.2;.3; 1.6	1.05	1.44	.40;.51	.07
6/03/77	1	.364	.382	.16;.48	.25	.241	.05;.54	.141	.99	1.29	.16;.31; 1.32	1.08	1.15	.14;1.31	.14
6/03/77	2	.367	.389	.06;.50	.358	.366	.21;.45	.023	.975	1.25	.12;.33;.56	1.184	1.285	.11;1.45	-.035
6/03/77	3	.24	.27	.05;.31	1.57	.147	.1;.2	.123	1.15	1.295	.41;1.33	1.20	1.21	1.06;1.30	.085
6/03/77	4	.24	.33	.06	1.73	.21	.1	.12	.878	1.255	.22;.78	1.13	1.13	-	.125
6/10/77	1	.581	.663	.07;.05;.8	.659	.676	.2;.98	-.013	1.14	1.245	.43;.51; 1.45	1.21	1.29	.51	-.045
6/10/77	2	.93	.93	-	.834	.937	.01	-.007	1.49	1.59	.3;1.7	1.57	1.53	1.69;1.7	.06
6/10/77	3	.764	.778	.65	.56	.62	.15;.73	.158	1.44	1.45	1.325	1.25	1.29	.65;1.63	.16
6/10/77	4	.975	.975	-	.58	.745	.25	.230	1.55	1.58	1.46	1.10	1.26	.79	.32
6/17/77	1	.526	.569	.15;.8	.248	.268	.15;.17	.301	1.11	1.24	.21;.56	1.23	1.25	1.01;1.28	-.01
6/17/77	2	.537	.544	.45	.458	.46	.37;.53	.084	1.21	1.28	.35	1.19	1.28	.44;1.35	0
6/17/77	3	.297	.311	.15;.35	.25	.245	.17;.34	.066	1.19	1.22	.95	99	1.20	.48;.37;1.28	.02
6/17/77	4	.495	.50	.45;.525	.365	.365	-	.135	1.06	1.19	.53	1.21	1.21	-	-.02
6/24/77	1	1.49	1.49	1.4;1.61	1.5	1.54	1.15	-.05	1.88	1.93	1.45	2.05	.264	1.75;2.15	-.71
6/24/77	2	.779	.773	.57;1.03	.60	.608	.375;.675	.165	1.36	1.35	1.17;1.45	1.27	1.28	1.05;1.35	.07
6/24/77	3	.97	1.00	.7	.83	.878	.4	.122	1.27	1.45	.2;.9;1.65	1.33	1.375	.9;1.4	.075
6/24/77	4	1.05	1.1	.9	.58	.688	.15	.412	1.21	1.38	.5	1.065	1.28	.2	.10
6/30/77	1	.939	.931	.78;1.05	.961	.957	.74;1.22	-.026	1.42	1.41	.28;1.69	1.35	1.38	1.02;1.43	.03
6/30/77	2	.767	.758	.32;1.32	.535	.539	.45;.60	.219	1.17	1.17	.32;1.98; 1.32	1.13	1.17	.5;1.95	0
6/30/77	3	.862	.875	.16;1.42	.519	.603	.1;.3;.65	.272	1.31	1.44	.31;.32; 2.08	1.15	1.20	.6;1.31	.24
6/30/77	4	.577	.64	.1;.8	.485	.519	.35	.121	1.297	1.51	.28;1.45	1.0	1.11	.55	.40

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*We have noted free and total residual chlorine concentrations at the condenser outlet higher than at the condenser inlet. Since this phenomenon (inlet minus outlet ≤ - 0.1 mg/l) has only occurred 28 times out of 354 data points (7.9%), we have attributed the phenomenon to field experimental error until hypotheses can be tested. An analysis of this "negative consumption" may be found in Appendix A.

		Inlet Free			Outlet Free			Difference	Inlet Total			Outlet Total			Difference
Date	Unit	Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	Steady State Free Inlet-Outlet	Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	Steady State Total Inlet-Outlet
7/06/77	1	.804	.814	.36;1.15	.324	.339	.18;.2; .55	.475	1.09	1.09	.79;1.43	.973	.988	.6;1.15	.102
7/06/77	2	.407	.42	.08;.6	.378	.386	.125;.475	.34	.681	.706	.08;1.03	1.05	1.16	1.075;.2	-.454
7/06/77	3	1.00	1.02	.62;1.3	.345	.411	.05;.075; .45	.609	1.27	1.33	.66;1.53	1.0	1.19	.1;.4	.14
7/06/77	4	1.1	1.1	-	.392	.394	.3;.475	.706	1.37	1.55	1.0	1.02	1.14	.45	.41
7/13/77	1	.991	.991	-	.813	.859	.2;1.06	.132	1.29	1.29	-	1.19	1.20	1.1;1.28	.09
7/13/77	2	.580	.678	.05;.75	.485	.485	.35;.62	.193	1.12	1.32	.1;1.35	1.15	1.17	.96;1.27	.15
7/13/77	3	.748	.864	.05;.4;.975	.893	.89	.813;.98	-.026	1.24	1.30	.55;1.45	1.31	1.32	1.37;1.18	-.02
7/13/77	4	.484	.542	.05;.1;.95	.76	.76	-	-.218	.706	.879	.1	1.26	1.26	-	-.381
7/20/77	1	.989	1.04	.36;1.13	1.05	1.07	.9	-.03	1.41	1.47	.45;1.65	1.45	1.46	1.35	.01
7/20/77	2	1.06	1.12	.19;1.26	.891	.977	.025	.143	1.35	1.42	.28;1.58	1.28	1.37	.325;1.45	.05
7/20/77	3	.622	.62	.2;1.05	.963	1.0	.55;1.15	-.38	.846	.83	.5;1.24	1.32	1.42	.60	-.59
7/20/77	4	.70	.55	.4;1.15	1.04	1.13	.45	-.58	1.06	1.3	.48;1.4	1.45	1.54	.85;1.625	-.24
7/27/77	1	.638	.575	.35;1.30	.154	.193	.01;.05; .42	.382	.956	.942	1.4;.6	.772	.826	.05;.96	.116
7/27/77	2	.46	.479	.1;.7	.337	.306	.25;.375	.173	1.27	1.33	.55;1.45	1.26	1.27	1.2;1.3	.06
7/27/77	3	2.01	2.4	.25;3.0	2.63	3.45	.225;.55; 3.8	-1.05	2.75	3.13	1.05;3.7	3.34	4.34	.6;1.1	-1.21
7/27/77	4	.567	.8	.1	.388	.436	.05	.364	1.0	1.28	.45	1.21	1.28	.45;1.50	0
8/18/77	1	.462	.481	.03;.66	.724	.722	.68;.78	-.241	.964	1.02	.52;.54; 1.18	1.22	1.36	1.08;1.3	-.34
8/18/77	2	.747	.792	.04;.08; 1.01		No Data		-	1.31	1.38	.42;1.54		No Data		
8/18/77	3	.64	.64	-	.761	.772	.68;.79	-.132	1.25	1.2	1.4	1.25	1.26	1.17;1.3	-.06
8/18/77	4	.514	.52	.05;.74	.75	.75	.61;.89	-.23	1.12	1.07	.25;1.6	1.07	1.24	.28;1.36	-.17
8/25/77	1	.247	.249	.1;.38	.078	.072	.06;.10	.177	.667	.668	.58;.75	.622	.622	-	.046
8/25/77	2	.291	.283	.225;.38	.252	.248	.225;.275	.035	.889	.892	.85;.92	.758	.821	.2;.875	.071
8/25/77	3	.249	.248	.2;.3	.245	.247	.225;.3	.001	.835	.883	.54;.94	.821	.825	.80	.058
9/02/77	1	.26	.276	.1	.229	.228	.18;.26	.048	.738	.768	.44	.72	.724	.7;.75	.044
9/02/77	2	.184	.185	.13;.23	.158	.157	.13;.225	.028	.854	.874	.66;.91	.807	.842	.35;.875	.032
9/02/77	3	.255	.246	.1;.48	.217	.221	.15;.26	.025	.728	.854	.1;.32;.88	.729	.729	-	.125
9/02/77	4	.205	.20	.17;.25	.142	.142	-	.058	.77	.77	-	.742	.742	-	.026
9/08/77	1	.469	.475	.28;.58	.462	.488	.08;.58	-.013	.829	.931	.01;1.02	.873	.926	.1;.98	.005
9/08/77	2	.409	.412	.15;.65	.544	.563	.15;.76	-.151	.830	.92	.4;1.28	.843	.887	.25;1.0	.033
9/08/77	3	.447	.463	.08;.58	.475	.46	.425;.65	.003	.905	.994	.085;1.1	.958	.931	.9;1.15	.058
9/08/77	4	.376	.367	.2;.58	.422	.422	-	-.055	.914	.923	.5;1.30	.955	.967	.825;1.05	-.044
9/16/77	1	.515	.509	.4;.6	.596	.596	.54;.63	-.087	1.05	1.06	.9;1.1	1.06	1.07	1;1.1	.001
9/16/77	2	.492	.518	.12;.63	.166	.171	.1	.347	.943	.957	.8	.814	.905	.15;.3	.052
9/16/77	3	.373	.39	.2;.44	.375	.375	-	.015	.94	1.03	.22;1.1	.906	.992	.22	.038
9/16/77	4	.646	.606	.4;1.09	.159	.153	.05;.2	.453	.99	1.07	.5;1.09	.818	.938	.1	.132
9/23/77	1	.522	.531	.26;.7	.450	.473	.05;.64	.058	.916	.872	.52;1.15	.809	.83	.1;1.05	.042
9/23/77	2	.444	.433	.2;.6	.345	.369	.05;.45	.064	.894	.91	.8;1.0	.845	.906	.2;.95	.004

Date	Unit	Inlet Free			Outlet Free			Difference Steady State Free Inlet-Outlet	Inlet Total			Outlet Total			Difference Steady State Total Inlet-Outlet
		Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used		Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	
9/23/77	3	.75	.75	.6;.9	.628	.64	.575;.675	.11	1.1	1.1	1.05;1.12	1.05	1.05	1.025;1.07	.05
9/23/77	4	.4	.475	.1;.55	.35	.388	.05;.425	.012	.75	.933	.2	.721	.80	.1;.95	.133
9/30/77	1	.264	.28	.02;.4	.164	.181	.05;.26	.099	.506	.54	.04;.67	.488	.476	.1;.65	.064
9/30/77	2	.102	.105	.03;.16	.039	.039	.02;.06	.101	.388	.403	.21;.43	.341	.367	.03	.036
9/30/77	3	.418	.42	.37;.44	.241	.244	.2;.275	.174	.664	.663	.65;.68	.618	.619	.6;.63	.044
9/30/77	4	.20	.20	-	.051	.05	.03;1.0	.15	.49	.51	.43;.53	.373	.376	.03;.7	.134
10/03/77	2		No Data		.406	.414	.2;.55	-		No Data		.807	.833	.5;.88	-
10/03/77	3		No Data		.205	.21	.14;.25	-		No Data		.682	.7	.55;.74	-
10/03/77	4		No Data		.367	.367	-	-		No Data		.85	.85	.8;.9	-
10/12/77	2		No Data		.367	.41	.1;.46	-		No Data		.907	.988	.5	-
10/12/77	3		No Data		.30	.42	.1;.46			No Data		.74	.767	.44;.96	-
10/12/77	4		No Data		.353	.383	.26	-		No Data		.958	.96	.87;1.0	-
10/13/77	1		No Data		.429	.423	.3;.6	-		No Data		1.13	1.14	1.1;1.5	-
10/13/77	2		No Data		.290	.315	.12;.35	-		No Data		1.01	1.05	.88	-
10/13/77	3		No Data		.235	.250	.04;.34	-		No Data		.868	.932	.2;1.04	-
10/13/77	4		No Data		.34	.4	.1	-		No Data		1.02	1.1	.6;1.2	-
10/28/77	1	.212	.211	.09;.34	.289	.297	.22;.375	-.086	1.06	1.02	.69;1.75	.726	.709	.65;.92	.311
10/28/77	2	.159	.162	.09;.28	.126	.127	.1;.15	.035	.594	.608	.49;.73	.58	.58	.52;.60	.028
10/28/77	3	.167	.187	.09;.26	.11	.113	.06;.13	.074	.577	.578	.49;.66	.541	.58	.25;.60	-.002
10/28/77	4	.194	.167	.07;.40	.124	.123	.1;.15	.071	.582	.60	.39;.72	.588	.593	.53;.63	.007
11/02/77	1		No Data		.407	.4	.44	-		No Data		.713	.7	.74	-
11/02/77	2		No Data		.406	.423	.3;.46	-		No Data		.740	.72	.66;.8	-
11/02/77	3		No Data		.31	.3	.34	-		No Data		.615	.6	.58;.64	-
11/02/77	4		No Data		.28	.26	.14;.44	-		No Data		.547	.56	.34;.74	-
11/18/77	1	.193	.188	.1;.33	.172	.165	.13;.20	.023	.745	.737	.65;.91	.642	.657	.45;.7	.08
11/18/77	2	.131	.124	.01;.29	.147	.148	.13;.16	-.024	.448	.451	.19;.68	.493	.504	.13;.55	-.053
11/18/77	3	.073	.068	.01;.16	.145	.150	.13;.16	-.082	.53	.55	.07;.69	.559	.617	.05;.66	-.067
11/18/77	4	.086	.087	.05;.12	.128	.145	.06	.058	.51	.548	.22;.65	.583	.613	.45;.625	-.065
12/22/77	2	.324	.336	.04	.163	.162	.13;.2	.194	.527	.533	.4;.6	.443	.443	.4;.48	.09
12/22/77	3	.305	.308	.1;.4	.141	.136	.18	.172	.475	.493	.3;.54	.466	.462	.43;.53	.031

		Inlet Free			Outlet Free				Inlet Total			Outlet Total			
Date	Unit	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Difference Steady State Free (Inlet - Outlet)	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Difference Steady State Total (Inlet - Outlet)
08-15-78	4	.40	.39	.47, .34	.33	.35	.39, .05	.04		No Data			No Data		
08-29-78	2	.29	.32	.42, .03	.18	.19	.25, .08	.13	.56	.63	.77, .03	.59	.67	.71, .13	- .04
08-29-78	3	.41	.44	.58, .03	.38	.41	.44, .09	.03	.69	.74	.82, .03	.71	.76	.78, .12	.02
08-29-78	4	.41	.43	.51, .07	.35	.38	.42, .08	.05	.67	.72	.80, .12	.66	.72	.78, .10	0
09-06-78	1	.17	.18	.23, .08	.16	.17	.25, .03	.01	.44	.47	.50, .11	.46	.49	.56, .08	- .02
09-06-78	2	.22	.23	.23, .08	.18	.19	.23, .10	.04	.49	.53	.56, .12	.51	.50	.53, .45	.02
09-06-78	3	.22	.23	.29, .03	.19	.20	.27, .08	.03	.52	.55	.65, .06	.54	.58	.62, .15	- .03
09-06-78	4	.27	.28	.32, .03	.25	.26	.33, .06	.02	.57	.61	.69, .08	.57	.61	.65, .11	0
09-19-78	1	.53	.55	.60, .35	.39	.43	.55, .09	.12	.87	.87	.89, .84	.73	.84	.87, .12	.07
09-19-78	2	.40	.43	.48, .03	.35	.37	.47, .05	.06	.70	.75	.82, .06	.67	.73	.76, .08	.02
09-19-78	3	.38	.41	.44, .07	.35	.37	.41, .12	.04	.72	.78	.80, .10	.66	.70	.76, .18	.08
09-19-78	4	.32	.35	.40, .03	.34	.37	.39, .07	- .02	.67	.75	.78, .06	.66	.72	.75, .15	.03
10-03-78	1	.15	.16	.21, .05	.12	.12	.18, .03	.04	.62	.67	.70, .12	.56	.61	.69, .12	.06
10-03-78	3	.16	.17	.20, .05	.14	.15	.16, .03	.02	.68	.72	.78, .15	.63	.67	.72, .10	.05
10-03-78	4	.19	.20	.23, .06	.13	.13	.16, .05	.07	.71	.77	.84, .12	.62	.68	.71, .12	.09
10-17-78	1	.48	.51	.53, .31	.40	.39	.60, .22	.12	.96	.96	.98, .93	.87	.87	.88, .84	.09
10-17-78	2	.65	.66	.68, .57	.58	.61	.64, .35	.05	1.32	1.03	1.05, .97	.93	.92	.96, .85	.11
10-17-78	3	.75	.75	.76, .72	.57	.61	.75, .10	.14	1.10	1.08	1.05,1.25	.83	.90	1.01, .16	.18
10-31-78	1	.34	.36	.41, .06	.51	.57	.64, .05	- .21	.80	.87	.91, .11	.74	.79	.88, .11	.08
10-31-78	2	.39	.40	.44, .26	.46	.49	.61, .08	- .09	.88	.88	.93, .84	.72	.77	.82, .15	.11
10-31-78	3	.40	.39	.46, .34	.51	.56	.64, .03	- .17	.84	.90	.92, .40	.68	.74	.86, .05	.16
10-31-78	4	.39	.42	.47, .03	.45	.48	.63, .03	- .06	.83	.91	.94, .09	.62	.74	.83,.12,.08	.17
11-14-78	1	.19	.21	.27, .06	.39	.42	.55, .06	- .21	.65	.75	.78, .06	.62	.68	.13, .76	.07
11-14-78	3	.20	.22	.23, .06	.25	.27	.35, .05	- .05	.69	.78	.82, .06	.54	.59	.12, .70	.19
11-14-78	4	.20	.21	.25, .05	.21	.22	.25, .15	- .01	.69	.79	.83, .05	.62	.66	.75, .27	.13
11-28-78	1	.29	.31	.33, .15	.24	.24	.38, .02	.07	.72	.72	.70, .75	.58	.70	.02,.31,.15,.75	.02
11-28-78	2	.34	.36	.44, .02	.41	.42	.65, .11	- .05	.62	.81	.86,.03,.04,.07	.74	.78	.19,.40,.89	.03
11-28-78	4	.37	.42	.43, .04	.45	.48	.55, .06	- .06	.77	.87	.91, .04	.69	.75	.10,.50,.80	.12
12-07-78	1		No Data		.42	.46	.55, .08			No Data		.77	.78	.65, .82	
12-07-78	2		No Data		.37	.38	.39, .28			No Data		.75	.76	.66,.73,.74,.78	
12-07-78	4		No Data		.40	.44	.51, .03			No Data		.73	.83	.08,.77,.88	
12-19-78	1	.49	.49	.54, .46	.41	.44	.51, .14	.05	.89	.89	-	.79	.78	.85	.11
12-19-78	2	.50	.50	.53, .40	.38	.39	.45, .22	.11	.85	.86	.76,.73,.92	.76	.80	.63, .55	.06
12-19-78	4	.57	.58	.61, .48	.42	.45	.51, .15	.13	.92	.93	.86	.76	.82	.34	.11

Date	Unit	Inlet Free			Outlet Free			Difference Steady State Free (Inlet - Outlet)	Inlet Total			Outlet Total			Difference Steady State Total (Inlet - Outlet)
		Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used		Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used	
06-13-78	1	.26	.28	.32, .05	.24	.25	.28, .11	.03	.73	.78	.81, .10	.71	.75	.78, .20	.03
06-13-78	2	.54	.57	.64, .02	.49	.52	.59, .05	.05	1.05	1.12	1.18, .08	.97	1.04	1.10, .08	.08
06-13-78	3	.35	.36	.38, .25	.29	.30	.38, .18	.06	.85	.85	.88, .82	.75	.80	.85, .30	.05
06-13-78	4	.37	.41	.56, .05	.37	.40	.58, .03	.01	.80	.92	1.07, .08	.75	.86	1.03, .08	.06
06-20-78	1	.33	.35	.40, .03	.34	.35	.43, .08	0	.78	.81	.84, .47	.75	.81	.84, .10	0
06-20-78	2	.37	.41	.43, .03	.42	.41	.48, .38	0	.84	.92	.96, .04	.92	.92	.95, .88	0
06-20-78	3	.43	.43	.51, .35	.41	.41	.45, .33	.02	.90	.90	.93, .87	.84	.85	.86, .81	.05
06-20-78	4	.33	.41	.43, .07	.42	.47	.50, .08	- .06	.83	.97	1.00, .38	.79	.92	.94, .10	.05
06-21-78	1	.40	.40	.43, .33	.43	.43	.48, .33	- .03	.79	.79	.82, .75	.80	.76	.83, .78	0
06-21-78	2	.31	.33	.40, .03	.32	.32	.39, .20	.01	.69	.73	.82, .03	.73	.73	.78, .66	0
06-21-78	3	.44	.45	.49, .35	.39	.41	.45, .27	.04	.84	.84	.88, .82	.73	.74	.78, .62	.10
06-21-78	4	.39	.40	.44, .32	.36	.39	.43, .22	.01	.79	.77	.83, .76	.78	.80	.84, .67	- .03
06-27-78	1	.49	.49	.55, .42	.25	.25	.31, .15	.24	.70	.70	.73, .67	.72	.73	.75, .69	- .03
06-27-78	2	.69	.69	.75, .62	.33	.34	.40, .09	.35	.85	.85	.94, .78	.81	.85	.91, .18	0
06-27-78	3	.55	.59	.65, .17	.34	.34	.42, .27	.25	.74	.79	.86, .25	.79	.83	.87, .40	- .04
06-27-78	4	.63	.62	.69, .59	.27	.29	.36, .07	.33	.87	.90	.92, .72	.66	.72	.89, .10	.18
07-07-78	1	.18	.18	.25, .11	.19	.19	.26, .10	- .01	.63	.63	.68, .57	.61	.65	.68, .25	- .02
07-07-78	2	.15	.15	.24, .06	.46	.48	.60, .02	- .33	.86	.91	1.00, .25	.80	.85	.92, .08	.06
07-07-78	3	.16	.16	.20, .09	.39	.39	.43, .33	- .23	.87	.89	.92, .65	.84	.85	.89, .78	.04
07-07-78	4	.14	.15	.18, .09	.51	.52	.60, .37	- .37	.86	.91	.95, .62	.77	.81	.91, .50	.10
07-18-78	1	.12	.11	.23, .04	.11	.11	.16, .06	0	.68	.68	.72, .64	.73	.73	.75, .69	- .05
07-18-78	2	.15	.15	.30, .02	.11	.10	.29, .06	.05	.68	.65	.71, .56	.69	.72	.80, .27	- .07
07-18-78	3	.07	.07	.10, .06	.07	.07	.09, .05	0	.73	.74	.81, .62	.59	.63	.76, .06	.11
07-18-78	4	.09	.10	.11, .07	.10	.09	.14, .08	.01	.75	.76	.77, .73	.73	.73	.74, .70	.03
07-25-78	2	.20	.21	.24, .05	.17	.17	.22, .09	.04	.68	.74	.76, .10	.62	.68	.71, .11	.06
07-25-78	3	.17	.18	.23, .04	.15	.15	.22, .03	.03	.62	.66	.81, .08	.55	.59	.75, .06	.07
07-25-78	4	.19	.20	.23, .05	.17	.18	.22, .04	.02	.75	.81	.84, .10	.63	.67	.76, .09	.14
08-02-78	1	.18	.19	.24, .10	.15	.16	.24, .04	.03	.62	.67	.40, .63, .58	.60	.72	.67, .14, .10	- .05
08-02-78	2	.30	.31	.19, .33	.25	.26	.33, .09	.05	.72	.74	.69, .65	.61	.69	.65, .14, .60	.05
08-02-78	3	.42	.42	.45, .38	.30	.31	.43, .03	.09	.79	.80	.75	.58	.75	.06, 70, .73	.05
08-02-78	4	.40	.43	.48, .03	.36	.38	.42, .03	.05	.78	.87	.81, .77, .06	.72	.79	.07, .75, .76	.08
08-08-78	1	.11	.11	.13, .08	.10	.11	.15, .03	0	.66	.66	.68, .63	.62	.61	.68, .54	.05
08-08-78	3	.07	.08	.08, .06	.07	.08	.08, .05	0	.66	.66	.68, .63	.63	.63	.65, .58	.03
08-08-78	4	.13	.11	.30, .09	.07	.07	.10, .03	.04	.70	.70	.73, .63	.64	.66	.71, .35	.04
08-15-78	2	.36	.39	.44, .06	.30	.32	.40, .03	.07	.68	.72	.79, .24	.60	.64	.72, .07	.08
08-15-78	3	.42	.42	.44, .38	.33	.36	.39, .05	.06	.72	.73	.75, .67	.64	.69	.73, .10	.04

		Inlet Free			Outlet Free				Inlet Total			Outlet Total			
Date	Unit	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Difference Steady State Free (Inlet - Outlet)	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Avg of All Numbers	Avg of Steady State	Numbers Not Used	Difference Steady Stat Total (Inlet - Outlet)
02-03-78	2	1.07	.66	3.0 , .34	.36	.35	.5 , .23	.31	1.89	1.37	4.0 ,1.33	1.13	1.08	1.4 ,1.0	.29
02-03-78	3	.29	.30	.41, .08	.06	.05	.10, .05	.25	.60	.64	.70, .21	.54	.53	.55, .60	.11
02-03-78	4	.32	.37	.37, .22	.16	.13	.3 , .1	.24	.54	.52	.60, .50	.26	.30	.35, .10	.22
02-17-78	1	.31	.31	.38, .25	.06	.06	.1 , .05	.25	.58	.59	.61, .53	.44	.44	.50, .40	.15
02-17-78	2	.28	.28	.58, .07	.09	.09	.1 , .07	.19	.49	.50	.66, .18	.49	.48	.55, .47	.02
02-17-78	4	.18	.17	.28, .08	.08	.10	.10, .05	.07	.40	.43	.56, .17	.41	.55	.55, .15	- .12
03-24-78	2	.30	.29	.55, .12	.13	.14	.08, .15	.15	.78	.71	1.8 , .39	.53	.53	.55, .52	.18
03-24-78	4	.17	.17	.32, .05	.07	.07	.07, .05	.10	.43	.43	.68, .18	.42	.48	.51, .07	- .05
04-13-78	2	.25	.25	.42, .05	.07	.06	.13, .04	.19	.63	.61	.93, .49	.54	.54	.55, .50	.07
04-13-78	3	.33	.24	.37, .08	.06	.05	.10, .05	.19	.61	.61	.90, .25	.67	.66	.80, .55	- .05
04-13-78	4	.18	.18	.31, .06	.04	.04	.05, .025	.14	.40	.43	.57, .11	.55	.55	.57, .55	- .12
04-28-78	2	.43	.37	.80, .30	.14	.13	.20, .10	.24	.76	.74	1.0 , .60	.72	.74	.75, .60	0
04-28-78	3	.15	.15	.24, .05	.09	.09	.13, .05	.06	.77	.84	.90, .30	.84	.88	.91, .65	- .04
04-28-78	4	.22	.28	.04, .30	.09	.09	.10, .07	.19	.61	.74	.79, .18	.75	.75	.75, .73	- .01
05-04-78	3	.10	.07	.18, .06	.13	.14	.20, .05	- .07	1.2	1.2	-	.95	1.09	1.29, .05	.11
[illegible]5-05-78	2	.05	.04	.10, .02	.07	.07	.08, .05	- .03	1.01	.99	1.25, .86	.87	.90	1.0 , .55	.09
05-05-78	3	.04	.03	.06, .03	.10	.11	.14, .05	- .08	1.13	1.16	1.25, .92	1.16	1.22	1.86, .32	- .06
05-05-78	4	.04	.04	.06, .02	.05	.05	.06, .05	- .01	1.16	1.20	1.20,1.05	1.05	1.05	1.08,1.02	.15
05-09-78	2	.06	.06	.08, .02	.28	.32	.35, .03	- .26	1.03	1.04	1.18, .80	1.65	1.21	4.4 ,1.15	- .17
05-09-78	3	1.43	1.43	1.51,1.34	0	0	-	1.43	2.27	2.23	2.54,2.10	2.13	2.13	2.13,2.1	.10
05-09-78	4	.04	.04	.05, .02	.18	.22	.04, .24	- .18	1.11	1.10	1.13,1.1	.82	1.03	1.10, .14	.07
05-16-78	2	.25	.25	.32, .18	.19	.19	.04, .27	.06	1.08	1.06	1.30,1.04	.90	.95	1.08, .18	.11
05-16-78	3	.88	.96	1.02, .50	.64	.66	1.07, .07	.30	1.04	1.09	1.16, .60	1.10	1.10	1.15, .98	- .01
05-16-78	4		No Data		.36	.30	.76, .02	-	1.16	1.16	1.23,1.10	2.21	2.2	2.9 ,1.55	-1.04
05-23-78	1		No Data			No Data		-	1.31	1.10	4.0 , .98	1.23	.98	4.0 , .93	.12
05-23-78	2		No Data			No Data			.97	.97	1.06, .93	.96	1.01	1.08, .32	- .04
05-23-78	3		No Data			No Data			1.26	1.00	4.0 , .65	1.48	1.27	4.0 , .96	- .27
05-23-78	4		No Data			No Data			1.12	1.06	1.54,1.04	.89	.96	1.0 , .53	.10
05-31-78	1	.54	.57	.61, .26	.46	.48	.57, .24	.09	1.13	1.14	1.16,1.01	1.10	1.10	1.14,1.05	.04
05-31-78	2	.61	.61	.62, .58	.51	.51	.58, .43	.10	1.19	1.18	1.22,1.16	1.10	1.10	1.18,1.01	.08
05-31-78	3	.82	.84	.93, .55	.68	.69	.77, .56	.15	1.36	1.45	1.48, .63	1.32	1.34	1.39,1.13	.11
05-31-78	4	.66	.67	.70, .60	.57	.57	.61, .51	.10	1.29	1.29	1.31,1.25	1.18	1.20	1.21,1.16	.09
06-06-78	1	.52	.55	.61, .10	.40	.42	.45, .14	.13	.97	1.04	1.07, .20	.94	.98	1.04, .43	.01
06-06-78	2	.64	.68	.72, .11	.29	.30	.41, .02	.38	1.12	1.13	1.18,1.02	.93	.99	1.21, .05	.14
06-06-78	3	.65	.66	.72, .56	.35	.37	.47, .08	.29	1.13	1.13	1.16,1.08	1.04	1.05	1.10, .94	.08
06-06-78	4	.97	1.06	1.68, .06	.46	.36	1.18, .02	.70	1.31	1.54	2.10, .16	1.33	1.4	2.45, .08	.14

APPARENT CLEANLINESS FACTOR

Date	C.F.	Date	C.F.	Date	C.F.
Unit 1					
3/28/74	82.10	6/1/77	72.00	6/6/78	72.00
6/11/74	70.11	6/17/77	72.00	6/14/78	72.00
7/25/74	72.40	6/30/77	71.00	6/21/78	71.00
2/13/75	79.13	7/13/77	72.00	7/7/78	71.00
3/20/75	75.48	7/27/77	71.00	7/18/78	73.00
4/23/75	76.62	8/9/77	72.00	8/2/78	72.00
7/22/75	72.67	8/24/77	70.00	8/14/78	71.00
8/26/75	70.31	9/8/77	70.00	8/28/78	71.00
9/30/75	69.04	9/22/77	69.00	10/19/78	73.00
11/5/75	72.63	10/5/77	72.00		
12/8/75	74.98	10/19/77	74.00		
1/12/76	87.00	11/2/77	70.00		
2/18/76	75.00	11/18/77	73.00		
3/23/76	72.00	12/2/77	81.00		
4/28/76	69.00	12/14/77	81.00		
5/6/76	71.00	12/30/77	87.00		
6/3/76	72.00	1/4/78	86.00		
6/10/76	69.00	1/10/78	89.00		
6/16/76	70.00	1/17/78	92.00		
7/9/76	71.00	1/25/78	85.00		
7/22/76	69.00	2/8/78	80.00		
7/29/76	69.00	2/13/78	73.00		
8/5/76	69.00	2/17/78	76.00		
8/12/76	72.00	2/22/78	79.00		
11/11/76	81.94	3/13/78	76.00		
12/13/76	83.37	5/31/78	72.00		

APPARENT CLEANLINESS FACTOR

Date	C.F.	Date	C.F.	Date	C.F.
Unit 2					
3/18/74	86.15	6/1/77	74.00	6/14/78	74.00
5/9/74	76.30	6/17/77	71.00	6/21/78	70.00
6/13/74	71.25	6/30/77	71.00	7/7/78	84.00
7/29/74	73.54	7/13/77	73.00	7/18/78	71.00
8/29/74	73.08	7/27/77	74.00	8/2/78	71.00
7/22/75	74.36	8/9/77	73.00	8/14/78	73.00
8/27/75	72.08	8/19/77	71.00	8/28/78	71.00
9/30/75	72.64	9/8/77	71.00	10/16/78	74.00
11/11/75	74.81	9/22/77	72.00	10/19/78	70.00
12/16/75	79.61	10/5/77	73.00		
1/21/76	90.00	10/18/77	76.00		
2/24/76	82.00	11/2/77	78.00		
5/6/76	71.00	11/18/77	80.00		
6/8/76	72.00	12/2/77	80.00		
6/16/76	70.00	12/14/77	84.00		
7/9/76	71.00	12/29/77	89.00		
7/22/76	72.00	1/10/78	90.00		
7/29/76	72.00	1/23/78	84.00		
8/6/76	73.00	2/8/78	83.00		
8/12/76	72.00	2/22/78	88.00		
8/19/76	70.00	3/22/78	80.00		
10/13/76	75.98	4/5/78	75.00		
11/15/76	82.98	4/19/78	76.00		
12/27/76	88.41	5/2/78	77.00		
6/1/77	74.00	5/16/78	73.00		
6/17/77	71.00	6/6/78	69.00		

APPARENT CLEANLINESS FACTOR

Date	C.F.	Date	C.F.	Date	C.F.
Unit 3					
2/26/74	91.48	5/6/77	72.00	5/16/78	77.00
5/21/74	76.16	5/20/77	75.00	6/6/78	74.00
7/11/74	72.95	6/3/77	75.00	6/14/78	73.00
8/28/74	73.15	6/16/77	74.00	6/21/78	74.00
11/22/74	81.11	6/30/77	74.00	7/7/78	74.00
1/15/75	84.94	7/13/77	74.00	7/18/78	74.00
2/27/75	83.34	8/10/77	75.00	8/2/78	73.00
5/13/75	78.90	9/8/77	73.00	8/15/78	75.00
6/17/75	75.09	9/21/77	73.00	8/28/78	74.00
7/22/75	74.98	10/6/77	77.00	10/16/78	78.00
9/30/75	68.96	10/19/77	78.00	10/19/78	78.00
11/7/75	74.30	11/3/77	79.00		
12/8/75	78.53	11/17/77	79.00		
1/12/76	87.00	12/01/77	86.00		
2/19/76	79.00	12/14/77	86.00		
3/23/76	76.00	12/29/77	89.00		
4/26/76	73.00	1/11/78	91.00		
6/9/76	72.00	1/23/78	93.00		
6/16/76	74.00	2/8/78	90.00		
7/9/76	71.00	2/22/78	89.00		
7/22/76	73.00	3/10/78	80.00		
7/29/76	72.00	3/24/78	67.00		
8/6/76	71.00	3/30/78	73.00		
8/12/76	72.00	4/5/78	70.00		
8/19/76	73.00	4/19/78	74.00		
10/13/76	74.10	5/2/78	80.00		

APPARENT CLEANLINESS FACTOR

Date	C.F.	Date	C.F.	Date	C.F.
Unit 4					
5/21/74	78.28	5/20/77	74.00	8/2/78	74.00
7/11/74	76.32	6/3/77	75.00	8/15/78	74.00
8/28/74	74.44	6/16/77	74.00	8/28/78	71.00
1/21/75	78.87	6/30/77	74.00	10/19/78	73.00
3/19/75	79.87	7/13/77	74.00		
4/18/75	78.19	7/27/77	74.00		
5/21/75	78.55	8/10/77	77.00		
6/30/75	74.57	9/9/77	74.00		
8/13/75	72.12	9/21/77	73.00		
9/30/75	72.77	10/6/77	77.00		
11/5/75	75.87	10/19/77	79.00		
12/15/75	79.52	11/3/77	78.00		
1/22/76	90.00	11/17/77	82.00		
5/20/76	73.00	12/01/77	82.00		
5/26/76	74.00	2/1/78	91.00		
6/9/76	74.00	2/22/78	88.00		
6/16/76	74.00	3/24/78	79.00		
6/30/76	75.00	4/5/78	76.00		
7/12/76	75.00	4/19/78	77.00		
7/22/76	73.00	5/2/78	78.00		
7/29/76	74.00	5/16/78	76.00		
8/6/76	71.00	5/31/78	72.00		
8/12/76	72.00	6/14/78	76.00		
8/19/76	73.00	6/21/78	74.00		
10/20/76	80.45	7/7/78	75.00		
11/22/76	83.87	7/18/78	74.00		

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
		Phase I		
6/9/76	2	6000	113,967	4.38
	3	4500	99,799	3.75
	4	6000	124,694	4.00
6/15/76	1	6000	128,581	3.88
6/16/76	1	4500	128,581	2.91
	2	4500	133,390	2.77
	3	4500	121,317	3.09
	4	4500	122,466	3.06
7/7/76	2	7500	138,798	4.50
	3	4500	139,631	2.68
	4	6000	129,241	3.86
7/8/76	1	6000	139,924	3.57
	2	7500	138,798	4.49
	3	4500	139,631	2.68
	4	6000	129,241	3.86
7/16/76	1	6000	124,128	4.02
	2	7500	137,866	4.52
	3	4500	119,689	3.13
8/13/76	1	6000	130,245	3.83
	3	4500	103,227	3.63
	4	6000	115,352	4.33
8/19/76	1	6000	139,655	3.58
	2	7500	128,108	4.87
	3	4500	132,630	2.82
	4	6000	130,766	3.82
		Phase II		
5/6/77	1	4500	154,000	2.43
	3	4500	141,000	2.66
	4	4500	151,000	2.48
5/12/77	1	4500	135,872	2.76
	3	4500	114,000	3.28
	4	4500	136,425	2.75
5/20/77	1	4500	140,007	2.67
	2	4500	122,911	3.05
	3	4500	131,289	2.85
	4	4500	126,583	2.96

Continued

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
		Phase II (Continued)		
5/27/77	1	4500	137,765	2.72
	2	4500	128,856	2.91
	3	4500	132,873	2.82
	4	4500	128,117	2.92
6/3/77	1	4500	137,591	2.72
	2	4500	125,638	2.98
	3	4500	134,127	2.79
	4	4500	130,984	2.86
6/10/77	1	4500	137,609	2.72
	2	4500	110,547	3.39
	3	4500	133,895	2.80
	4	4500	129,926	2.88
6/17/77	1	4500	138,196	2.71
	2	4500	138,243	2.71
	3	4500	133,404	2.81
	4	4500	129,732	2.89
6/24/77	2	4500	136,154	2.75
	3	4500	137,242	2.73
	4	4500	127,881	2.93
6/30/77	1	4500	140,402	2.68
	2	4500	137,322	2.73
	3	4500	133,030	2.82
	4	4500	123,675	3.03
7/6/77	1	4500	139,381	2.69
	2	4500	140,354	2.67
	4	4500	125,952	2.97
7/13/77	1	4500	135,885	2.76
	2	4500	135,287	2.77
	3	4500	132,145	2.83
	4	4500	122,053	3.07
7/20/77	1	4500	137,828	2.72
	2	4500	133,534	2.80
	3	4500	131,285	2.85
	4	4500	122,505	3.01
7/27/77	1	3000	136,518	1.83
	2	4500	136,904	2.74
	4	4500	117,125	3.20
8/18/77	1	4500	135,131	2.77
	3	4500	132,390	2.83
	4	4500	126,904	2.95

Continued

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
Phase II (Continued)				
8/25/77	1	2500	132,934	1.56
	2	3000	130,492	1.91
9/2/77	1	2500	130,785	1.59
	2	2500	134,564	1.55
	3	2500	125,908	1.65
	4	2500	127,631	1.63
9/9/77	1	2500	125,812	1.65
	2	2500	135,583	1.53
	3	2500	122,450	1.70
	4	2500	124,760	1.67
9/16/77	1	1500	124,049	1.01
	2	2500	134,233	1.55
	3	2500	121,183	1.72
	4	2500	126,038	1.65
9/23/77	1	1500	124,200	1.01
	2	2500	131,287	1.58
	3	2500	117,328	1.77
	4	2500	123,407	1.68
Phase III				
10/6/77	1	1500	103,268	1.21
	2	1500	108,776	1.15
	3	1500	110,813	1.13
	4	1500	109,223	1.14
10/28/77	1	1500	101,133	1.23
	2	1500	110,628	1.13
	3	1500	112,831	1.11
	4	1500	113,287	1.10
11/3/77	1	1500	100,587	1.24
	2	1500	112,868	1.10
	3	1500	113,496	1.10
	4	1500	109,409	1.14
11/18/77	1	1500	94,299	1.32
	2	1500	113,261	1.10
	3	1500	100,137	1.25
	4	1500	101,970	1.22
12/1/77	1	1500	108,257	1.15
	2	1500	112,362	1.11
	3	1500	112,937	1.11
	4	1500	111,681	1.12

Continued

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
Phase III (Continued)				
12/22/77	2	1500	114,738	1.09
	3	1500	112,152	1.11
2/3/78	2	1500	105,676	1.18
	3	1500	102,695	1.22
	4	1500	98,319	1.27
2/17/78	1	1500	102,777	1.21
	2	1500	107,375	1.16
	4	1500	95,636	1.31
3/24/78	2	1500	108,314	1.15
	4	1500	108,310	1.15
4/13/78	2	1500	111,656	1.12
	3	1500	108,639	1.15
	1	2000	108,748	1.53
	4	1500	109,634	1.14
4/28/78	2	2000	110,539	1.51
	3	2500	108,537	1.92
	4	2000	110,427	1.51
5/5/78	3	3000	112,492	2.22
	2	3000	148,344	1.68
	4	3000	125,315	1.99
5/9/78	2	3500	117,349	2.48
	4	3500	124,050	2.35
5/16/78	2	3500	134,354	2.17
	3	3500	128,219	2.27
	4	3500	123,584	2.37
5/23/78	1	3500	140,541	2.07
	2	3500	131,538	2.21
	3	3500	133,860	2.18
	4	3500	128,087	2.27
5/31/78	1	3500	143,378	2.03
	4	3500	126,009	2.30
6/6/78	1	3600	140,054	2.14
	2	3500	136,929	2.13
	3	3500	132,612	2.20
6/13/78	1	3000	139,479	1.79
	2	3500	122,574	2.38
	3	3000	134,986	1.85
	4	3500	132,104	2.20
6/20/78	1	2800	141,147	1.65
	2	2800	134,764	1.73
	3	2800	134,559	1.73
	4	2800	130,883	1.78

Continued

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
		Phase III (Continued)		
6/21/78	1	3000	141,147	1.76
	2	3000	134,764	1.84
	3	3000	134,559	1.83
	4	3000	130,883	1.89
6/27/78	1	3100	144,602	1.78
	2	3000	135,813	1.84
	3	3000	136,340	1.83
	4	3000	128,655	1.94
7/7/78	1	2500	141,569	1.47
	2	3000	115,407	2.16
	3	3000	137,792	1.81
	4	3000	126,613	1.97
7/18/78	1	2500	133,424	1.56
	2	2500	133,680	1.56
	3	2500	139,010	1.50
	4	2500	127,074	1.64
7/25/78	1	2500	133,723	1.56
	2	2500	142,512	1.46
	3	2500	135,150	1.54
	4	2500	133,625	1.56
8/2/78	1	2500	136,125	1.53
	2	2500	145,339	1.43
	3	2500	131,536	1.58
	4	2500	129,253	1.61
8/8/78	1	2500	137,480	1.51
	3	2500	137,276	1.52
	4	2500	128,196	1.62
8/16/78	1	NA	143,061	NA
	2	2500	128,201	1.62
	3	2500	133,069	1.56
	4	2500	131,949	1.58
8/29/78	1	NA	137,686	NA
	2	2500	139,076	1.50
	3	2500	132,657	1.57
	4	2500	128,580	1.62
9/6/78	1	2500	127,932	1.63
	2	2500	136,550	1.52
	3	2500	133,386	1.56
	4	2500	130,284	1.60

Continued

CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate (lb/24 hrs.)	Flow Rate (Gal/min)	Cl_2 Conc. (mg/l)
		Phase III (Continued)		
9/19/78	1	2500	127,932	1.63
	2	2500	136,550	1.52
	3	2500	133,386	1.56
	4	2500	130,284	1.60
10/3/78	1	2500	112,284	1.86
	3	2500	108,133	1.92
	4	2500	107,633	1.93
10/17/78	1	2500	112,284	1.86
	2	2500	108,606	1.91
	3	2500	108,133	1.92
10/31/78	1	2500	112,284	1.86
	2	2500	108,606	1.91
	3	2500	108,133	1.92
	4	2500	107,633	1.93
11/14/78	1	2500	106,969	1.95
	3	2500	105,065	1.98
	4	2500	105,328	1.97
11/28/78	1	2500	106,969	1.95
	2	2500	104,771	1.99
	4	2500	105,328	1.97
12/19/78	1	2500	106,501	1.95
	2	2500	94,380	2.20
	3	2500		
	4	2500	82,248	2.53

$$\frac{\text{Feed Rate lb/24 hrs.}}{\text{Flow Rate gal/min.}} \times 83.22 = \text{mg/l } Cl_2$$

WATER QUALITY PARAMETERS

Date	pH	Cond.	Alkalinity	T.S.S.	T.O.C.	NH_3	Org N	NO_2 NO_3	Inlet Water Temp-°F
Phase I									
5/26/76	7.8	330	85	26	6.2	.14	.47	1.1	73
6/9/76	7.6	290	98	15	3.0	.26	.13	.78	70
6/15/76	7.6	340	94	7	5.6	.50	.43	.97	81
6/16/76	7.6	270	100	24	2.9	.25	.30	.78	77
7/8/76	7.6	330	82	22	4.2	.15	.38	.79	72
7/16/76	7.5	240	66	20	4.9	.14	.20	.55	73
8/13/76	7.3	200	54	10	3.1	.16	.24	.58	77
8/19/76	7.5	210	63	20	2.8	.19	.22	.60	73
Phase II									
5/6/77	7.8	280	94	25	2.9	.81	.07	.74	75
5/12/77	8.3	220	82	22	2.2	.07	.15	.70	59
5/20/77	7.7	240	82	21	2.8	.12	.18	.70	64
5/27/77	7.8	310	91	17	1.9	.21	.27	.67	72
6/3/77	7.9	320	90	20	5.2	.12	.24	.62	72
6/10/77	8.0	260	80	28	7.8	.09	.15	.53	64
6/17/77	8.0	260	82	21	3.8	.14	.11	.62	70
6/24/77	7.5	280	74	-	4.2	.39	.33	.37	72
6/30/77	7.6	270	73	26	3.7	.11	.18	.54	72
7/6/77	7.8	270	79	20	2.9	.13	.16	.62	77
7/13/77	7.7	200	66	25	4.1	.15	.14	.58	72
7/20/77	7.7	180	56	22	2.5	.06	.14	.50	75
1/27/77	7.6	250	64	28	2.1	.20	.22	.57	70
8/25/77	7.6	300	80	21	-	.11	.19	.53	72
9/2/77	7.4	240	72	19	-	.12	.16	.62	73
9/8/77	7.5	270	72	16	4.8	.13	.15	.70	70
9/16/77	7.4	280	74	13	4.0	.16	.19	.71	72
9/23/77	7.4	220	76	20	5.2	.10	.20	.63	68
9/30/77	7.5	210	75	21	6.6	.09	.09	.68	63
Phase III									
10/28/77	7.5	240	78	36	4.1	.07	.13	.65	59
11/18/77	7.4	220	80	34	4.3	.06	.32	.68	50
12/22/77	7.5	210	78	10	1.0	.04	.22	.76	43
2/3/78	7.5	250	76	16	3.2	.21	.29	.92	37
2/17/78	7.9	290	89	10	2.3	.07	.13	.98	43
3/24/78	8.2	320	100	13	2.9	.09	.17	.63	54
4/13/78	7.5	360	100	16	4.0	.49	.27	.63	63
4/28/78	7.3	320	86	28	2.4	.10	1.3	.57	54
5/5/78	7.2	290	86	23	1.4	.17	.20	.71	61
5/9/78	7.1	350	90	22	1.9	.15	.18	.61	64
5/16/78	7.2	340	91	29	2.9	.19	.19	.71	60

WATER QUALITY PARAMETERS

Date	pH	Cond.	Alkalinity	T.S.S.	T.O.C.	NH_3	Org N	NO_2 NO_3	Inlet Water Temp-°F
5/23/78	7.8	340	83	23	5.0	.15	.23	.79	66
5/31/78	7.6	290	88	11	3.4	.16	.14	.87	72
6/6/78	7.7	240	83	29	5.7	.09	.13	.69	69
6/13/78	7.2	320	85	32	2.6	.10	.21	.85	73
6/21/78	7.6	310	84	36	3.4	.10	.12	.72	75
6/27/78	7.6	260	89	26	3.0	.08	.13	.72	75
7/7/78	7.6	430	94	26	6.3	.15	.18	.95	81
7/18/78	8.2	320	91	20	4.0	.15	.29	.73	75
7/25/78	7.8	240	78	20	3.6	.07	.19	.65	77
8/2/78	7.5	290	85	29	3.5	.12	.16	.67	73
8/8/78	7.5	400	86	31	4.3	.16	.16	.77	75
8/15/78	7.6	320	82	27	3.2	.10	.10	.75	75
8/29/78	7.4	210	68	19	4.2	.07	.21	.68	73
9/6/78	8.1	340	84	25	3.8	.07	.21	.53	75
9/19/78	7.6	220	77	24	2.8	.08	.16	.74	70
10/3/78	7.5	420	87	24	4.4	.11	.27	.32	66
10/17/78	7.6	290	64	19	3.0	.13	.19	.86	59
10/31/78	7.4	400	90	15	5.0	.21	.19	.77	61
11/14/78	7.8	470	88	13	4.4	.11	.23	1.0	64
11/28/78	7.4	410	90	12	2.8	.16	.14	1.1	-
12/19/78	7.3	350	98	5	2.9	.08	.36	1.1	-

FREE RESIDUAL CHLORINE
CONSUMED IN SYSTEM

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-06-77	.86	-	.67	-
4500	05-12-77	-	-	1.41	1.02
4500	05-20-77	.47	-	.42	.78
4500	05-27-77	1.13	1.22	1.20	1.24
4500	06-03-77	1.12	1.12	1.25	1.22
4500	06-10-77	.68	.76	.78	.69
4500	06-17-77	1.09	.89	1.16	1.08
4500	06-24-77	-	.77	.48	.78
4500	06-30-77	.38	.83	.81	1.00
4500	07-06-77	1.01	.95	-	1.09
4500	07-13-77	.86	.90	.52	.77
4500	07-20-77	.30	.42	.42	.37
U1=3000 U2-4=4500	07-27-77	.72	1.06	-	1.16
4500	08-18-77	.66	-	.64	.72
U1=2500 U2-4=3000	08-25-77	.71	.71	-	-
2500	09-02-77	.57	.62	.60	.67
2500	09-09-77	.34	.20	.39	.41
U1=1500 U2-4=2500	09-16-77	-.09	.60	.48	.67
U1=1500 U2-4=2500	09-23-77	.03	.42	.24	.45
1500	10-30-77	.43	.53	.31	.50
1500	11-18-77	.48	.40	.47	.47
1500	12-22-77	-	.38	.42	-

TOTAL RESIDUAL CHLORINE
CONSUMED IN SYSTEM

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-06-77	-.09	-	-.07	-
4500	05-12-77	-	-	.87	.46
4500	05-20-77	.14	-	-.11	.26
4500	05-27-77	-.02	.02	-.02	.02
4500	06-03-77	.21	.20	.18	.3
4500	06-10-77	.07	.16	.11	.18
4500	06-17-77	.10	.07	.20	.23
4500	06-24-77	-	.09	-.01	.18
4500	06-30-77	-.04	.19	.21	.40
4500	07-06-77	.36	.17	-	.34
4500	07-13-77	.18	.21	.09	.27
4500	07-20-77	-.10	.03	.01	-.03
U1=3000 U2-4=4500	07-27-77	.09	.1	-	.32
4500	08-18-77	.02	-	.15	.23
U1=2500 U2-4=3000	08-25-77	.16	.13	-	-
2500	09-02-77	.07	-.07	.10	.07
2500	09-09-77	-.10	-.12	-.08	-.13
U1=1500 U2-4=2500	09-16-77	-.56	-.13	-.13	-.11
U1=1500 U2-4=2500	09-23-77	-.32	-.12	-.16	.04
1500	10-30-77	-.09	-.01	-.02	-.04
1500	11-18-77	-.01	0	0	-.01
1500	12-22-77	-	.09	.10	-

FREE RESIDUAL CHLORINE CONSUMED IN SYSTEM USED IN ANALYSIS TOTALS (SAMPLE SIZE)

Feed Rate (lbs/24 hrs)	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	May	0.82(3)	1.22(1)	0.93(4)	1.01(3)
	June	0.82(4)	0.87(5)	0.90(5)	0.95(5)
	July	0.93(2)	0.92(2)	0.52(1)	0.95(2)
2500	Sept	0.45(2)	0.41(2)	0.50(2)	0.55(2)
1500	Oct/Nov	0.46(2)	0.47(2)	0.40(2)	0.49(2)

TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM USED IN ANALYSIS TOTALS (SAMPLE SIZE)

Date	Unit 1	Unit 2	Unit 3	Unit 4
May	0.07(2)	0.02(1)	0.42(2)	0.25(3)
June	0.08(4)	0.15(5)	0.14(5)	0.26(5)
July	0.27(2)	0.19(2)	0.09(1)	0.31(2)

FREE RESIDUAL CHLORINE AT INLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.50	.41	.38	.47
4500	06-3-77	.38	.39	.27	.33
4500	06-10-77	.66	.93	.78	.98
4500	06-17-77	.57	.54	.31	.50
4500	06-30-77	.93	.76	.88	.64
4500	07-06-77	.81	.42	1.02	1.10
4500	07-13-77	.99	.68	.86	.54
2500	09-02-77	.28	.19	.25	.20
2500	09-08-77	.48	.41	.46	.37
U1=1500 U2-4=2500	09-16-77	.51	.52	.39	.61
U1=1500 U2-4=2500	09-23-77	.53	.42	.75	.48
1500	09-30-77	.28	.11	.42	.20
1500	10-28-77	.21	.16	.19	.17
1500	11-18-77	.19	.12	.07	.09

TOTAL RESIDUAL CHLORINE AT INLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	1.30	1.41	1.15	1.51
4500	06-03-77	1.29	1.25	1.30	1.26
4500	06-10-77	1.25	1.59	1.45	1.58
4500	06-17-77	1.24	1.28	1.22	1.19
4500	06-30-77	1.41	1.17	1.44	1.51
4500	07-13-77	1.29	1.32	1.30	.88
2500	09-02-77	.77	.87	.85	.77
2500	09-08-77	.93	.92	.99	.92
U1=1500 U2-4=2500	09-16-77	1.06	.96	1.03	1.07
U1=1500 U2-4=2500	09-23-77	.87	.91	1.1	.93
1500	10-28-77	1.02	.61	.58	.60
1500	11-18-77	.74	.45	.55	.55

FREE RESIDUAL CHLORINE
AT OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.23	.24	.21	.22
4500	06-03-77	.24	.37	.15	.21
4500	06-10-77	.68	.94	.62	.75
4500	06-17-77	.27	.46	.25	.37
4500	06-30-77	.96	.54	.60	.52
4500	07-06-77	.34	.39	.41	.39
4500	07-13-77	.86	.49	.89	.76
2500	09-02-77	.23	.16	.22	.14
2500	09-08-77	.49	.56	.46	.42
U1=1500 U2-4=2500	09-16-77	.60	.17	.38	.15
U1=1500 U2-4=2500	09-23-77	.47	.37	.64	.39
1500	09-30-77	.18	.04	.24	.05
1500	10-28-77	.30	.13	.11	.12
1500	11-18-77	.17	.15	.15	.15

TOTAL RESIDUAL CHLORINE
AT OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	1.38	1.43	1.43	1.44
4500	06-03-77	1.15	1.29	1.21	1.13
4500	06-10-77	1.29	1.53	1.29	1.26
4500	06-17-77	1.25	1.29	1.20	1.21
4500	06-30-77	1.38	1.17	1.20	1.11
4500	07-13-77	1.20	1.17	1.32	1.26
2500	09-02-77	.72	.84	.73	.74
2500	09-08-77	.93	.89	.93	.97
U1=1500 U2-4=2500	09-16-77	1.07	.91	.99	.94
U1=1500 U2-4=2500	09-23-77	.83	.91	1.05	.80
1500	10-28-77	.71	.58	.58	.59
1500	11-18-77	.66	.50	.62	.61

FREE RESIDUAL CHLORINE
DIFFERENCE BETWEEN INLET AND OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.27	.17	.17	.25
4500	06-03-77	.14	.02	.12	.12
4500	06-10-77	-.02	-.01	.16	.23
4500	06-17-77	.30	.08	.06	.13
4500	06-30-77	-.03	.22	.28	.12
4500	07-06-77	.47	.03	.61	.71
4500	07-13-77	.13	.19	-.03	-.22
2500	09-02-77	.05	.03	.03	.06
2500	09-08-77	-.01	-.15	0	-.05
U1=1500 U2-4=2500	09-16-77	-.09	.35	.01	.46
U1=1500 U2-4=2500	09-23-77	.06	.06	.11	.09
1500	09-30-77	.10	.07	.18	.15
1500	10-28-77	-.09	.03	.08	.05
1500	11-18-77	.02	-.03	-.08	-.06

FREE RESIDUAL CHLORINE
CONSUMED IN SYSTEM
AND INLET WATER TEMPERATURE

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.
05-06-77	.86	71	-	-	.67	69	-	69
05-12-77	-	62	-	-	1.41	60	1.02	64
05-20-77	.47	68	-	-	1.20	66	.78	69
05-27-77	1.13	74	1.22	71	1.20	71	1.24	72
06-03-77	1.12	72	1.12	71	1.25	71	1.22	71
06-10-77	.68	66	.76	62	.78	64	.69	64
06-17-77	1.09	74	.89	73	1.16	72	1.08	72
06-24-77	-	71	.77	71	.49	69	.78	71
06-30-77	.38	72	.83	71	.81	70	1.00	70
07-06-77	1.01	82	.95	79.5	-	80	1.09	79
07-13-77	.86	76	.9	74	.52	74	.77	74
07-20-77	.29	77.5	.42	74	.42	76	.37	74
07-27-77	.72	75	1.06	71	-	72	1.16	72
08-18-77	.66	73	-	-	.64	71	.72	70
08-25-77	.71	77	.71	75	-	75	-	-
09-02-77	.57	76	.62	75	.60	75	.67	74
09-09-77	.34	71	.20	71	.39	72	.41	71
09-16-77	-.09	73	.60	72	.48	72	.67	72
09-23-77	.03	71	.42	68	.24	69	.45	68
10-30-77	.43	61	.53	59	.31	65	.5	-
11-18-77	.48	55	.40	54	.47	53	.47	54
12-22-77	-	-	.38	44	.42	43	-	-

TOTAL RESIDUAL CHLORINE
CONSUMED IN SYSTEM
AND INLET WATER TEMPERATURE

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.
05-06-77	-.09	71	-	-	-.07	69	-	69
05-12-77	-	62	-	-	.87	60	.46	64
05-20-77	.14	68	-	-	-.11	66	.26	69
05-27-77	-.02	74	.02	71	-.02	71	.02	72
06-03-77	.21	72	.05	71	.18	71	.3	71
06-10-77	.07	66	.16	62	.11	64	.18	64
06-17-77	.10	74	.07	73	.20	72	.23	72
06-24-77	-	71	.09	71	-.01	69	.18	71
06-30-77	-.04	72	.19	71	.21	70	.40	70
07-06-77	.36	82	.17	79	-	80	.34	79
07-13-77	.18	76	.21	74	.09	74	.27	74
07-20-77	-.1	77	.03	74	.01	76	-.03	74
07-27-77	.09	75	.1	71	-	72	.32	72
08-18-77	.02	73	-	-	.15	71	.23	70
08-25-77	.16	77	.13	75	-	75	-	-
09-02-77	.07	76	-.07	75	.10	75	.07	74
09-09-77	-.10	71	-.12	71	-.08	72	-.13	71
09-16-77	-.56	73	-.13	72	-.13	72	-.11	72
09-23-77	-.32	71	-.12	68	-.16	69	.04	68
10-30-77	-.09	61	-.01	59	-.02	65	-.04	-
11-18-77	-.01	55	.0	54	.00	53	-.01	54
12-22-77	-	-	.09	44	.10	43	-	-

TOTAL RESIDUAL CHLORINE
DIFFERENCE BETWEEN INLET AND OUTLET

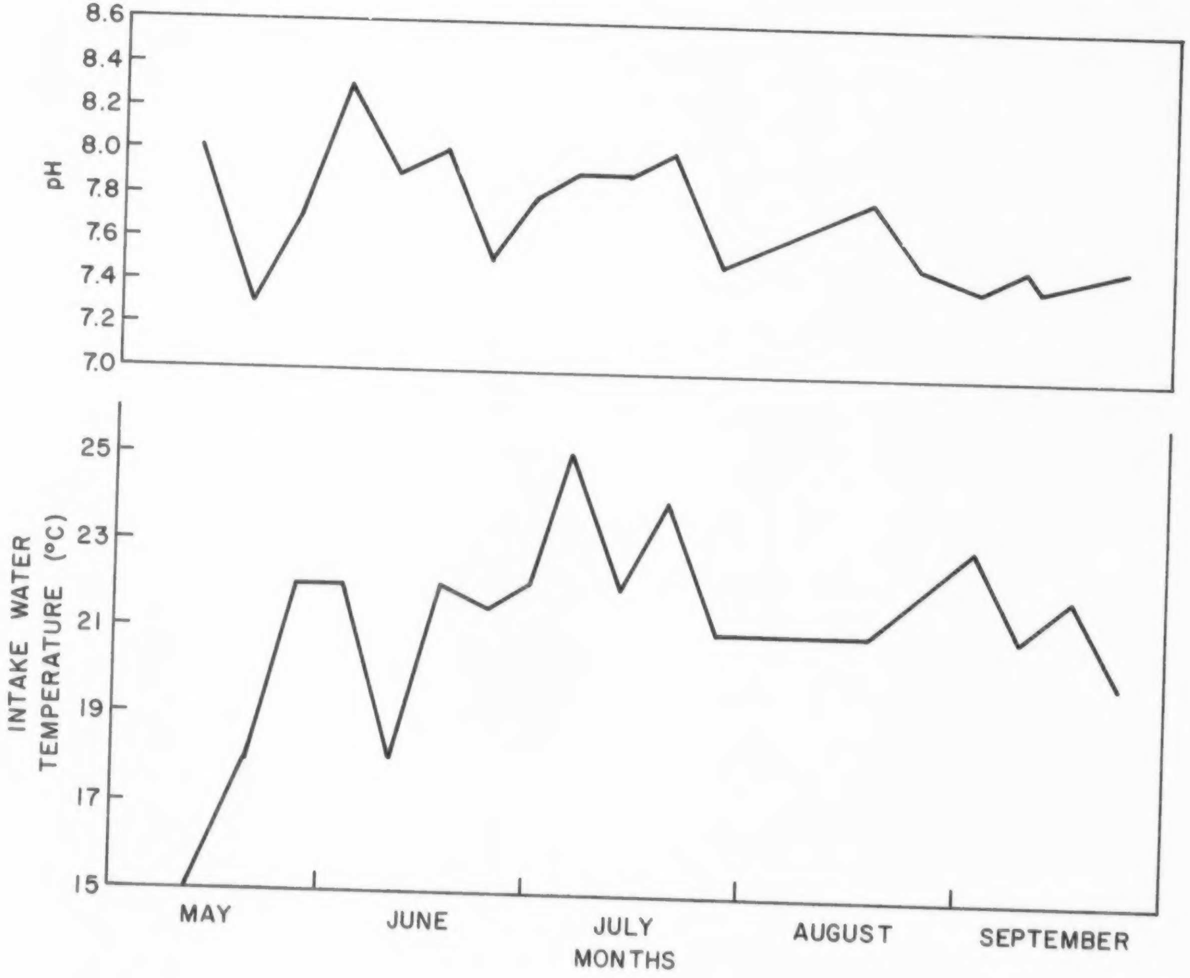
Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	-.08	-.02	-.28	.07
4500	06-03-77	.14	-.04	.09	.13
4500	06-10-77	-.04	.06	.16	.32
4500	06-17-77	-.01	0	.02	-.02
4500	06-30-77	.03	0	.24	.40
4500	07-13-77	.09	.15	-.02	-.38
2500	09-02-77	.05	.03	.12	.03
2500	09-09-77	0	.03	.06	-.05
U1=1500 U2-4=2500	09-16-77	-.01	.05	.04	.13
U1=1500 U2-4=2500	09-23-77	.04	0	.05	.13
1500	10-30-77	.31	.03	0	.01
1500	11-18-77	.08	-.05	-.07	-.06

CONDENSER PERFORMANCE DATA USED TO ESTIMATE THE CHANGE IN AFC RELATIVE TO A CHANGE IN INLET WATER TEMPERATURE (IWT)

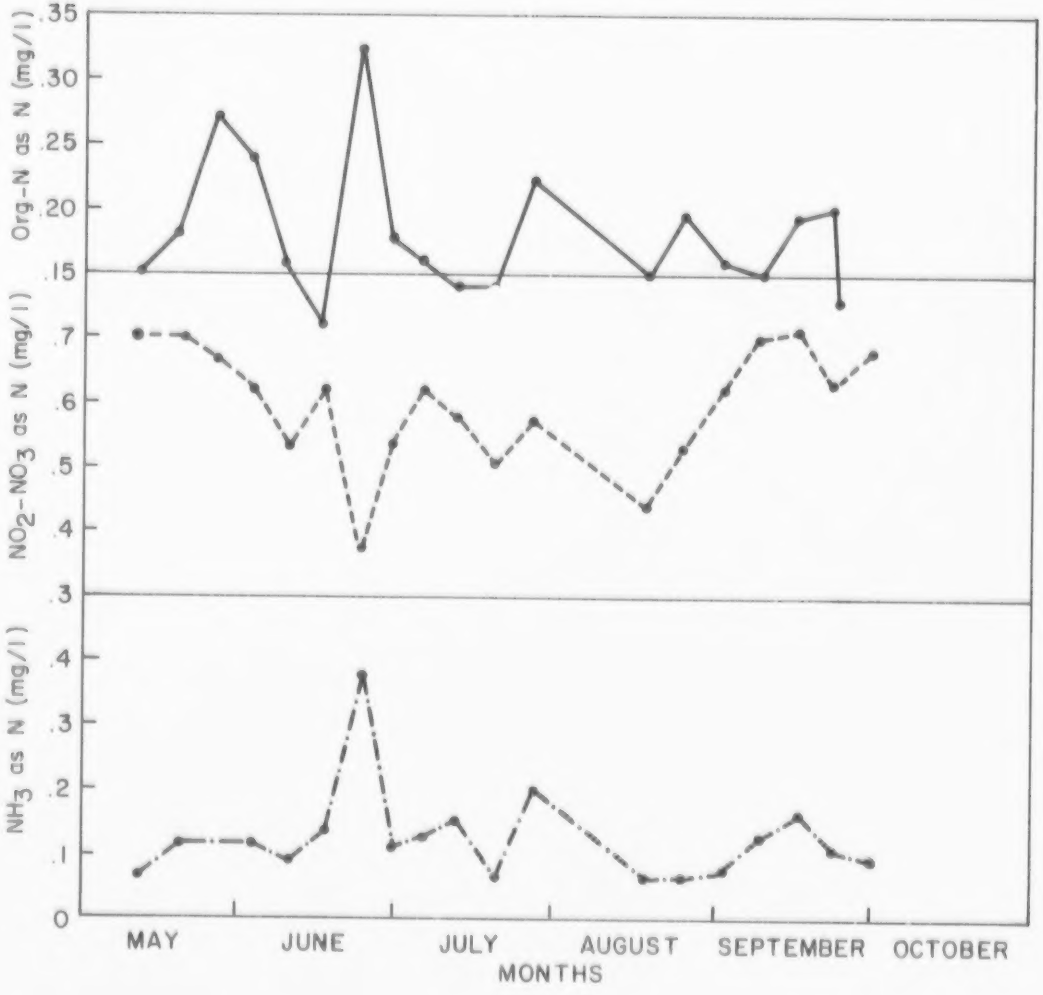
Date	Unit 1		Unit 2		Unit 3		Unit 4	
	ACF	IWT	ACF	IWT	ACF	IWT	ACF	IWT
05-20-77					.75	66		
06-03-77					.75	71	.75	71
06-16-77					.74	72		
06-17-77	.72	74	.71	73				
06-30-77	.71	72	.71	71	.74	70	.74	70
07-13-77	.72	76	.73	74	.74	74	.74	74
07-27-77	.71	75	.74	71			.74	72
08-10-77					.75	71	.77	72
08-24-77	.70	77	.71	75				
09-08-77					.73	72		
09-09-77							.74	71
09-21-77					.73	69	.73	68
09-22-77	.69	71	.72	68				
11-02-77	.70	61	.77	59				
11-03-77					.79	65	.78	65
11-17-77					.79	53	.82	54
11-18-77	.73	55	.80	54				
12-01-77					.85	53		

DATA USED TO ANALYZE CONDENSER PERFORMANCE WITH INLET WATER TEMPERATURE (IWT) AS A COVARIATE

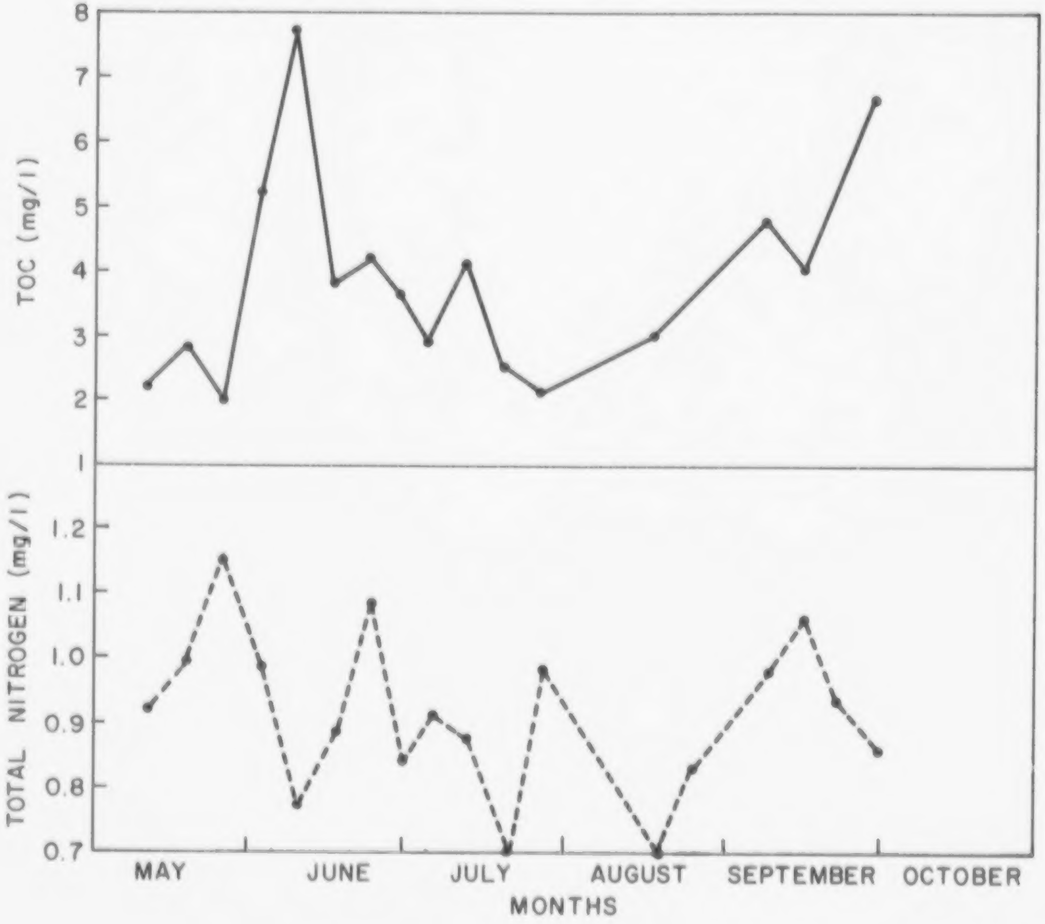
Date	Feed Rate	Unit 1		Unit 2		Unit 3		Unit 4	
		ACF	IWT	ACF	IWT	ACF	IWT	ACF	IWT
06-03	4500	.72	72	.74	71	.75	71	.75	71
06-17	4500	.72	74	.71	73	.74	72	.74	72
06-30	4500	.71	72	.71	71	.74	70	.74	70
07-13	4500	.72	76	.73	74	.74	74	.74	74
11-03	1500	.70	61	.77	59	.79	65	.78	65
11-18	1500	.73	55	.80	54	.79	53	.82	54



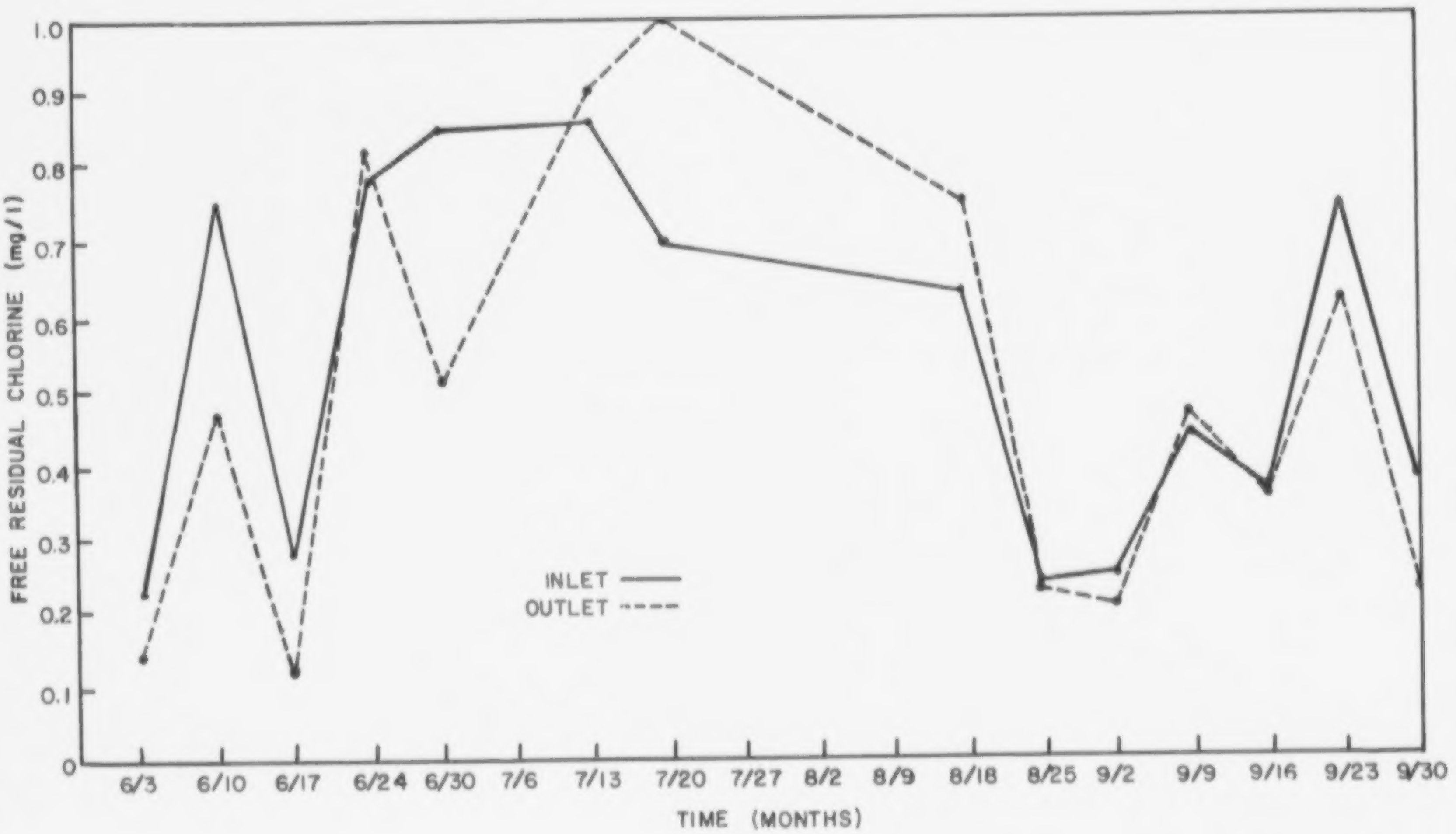
Water quality data for 1977.



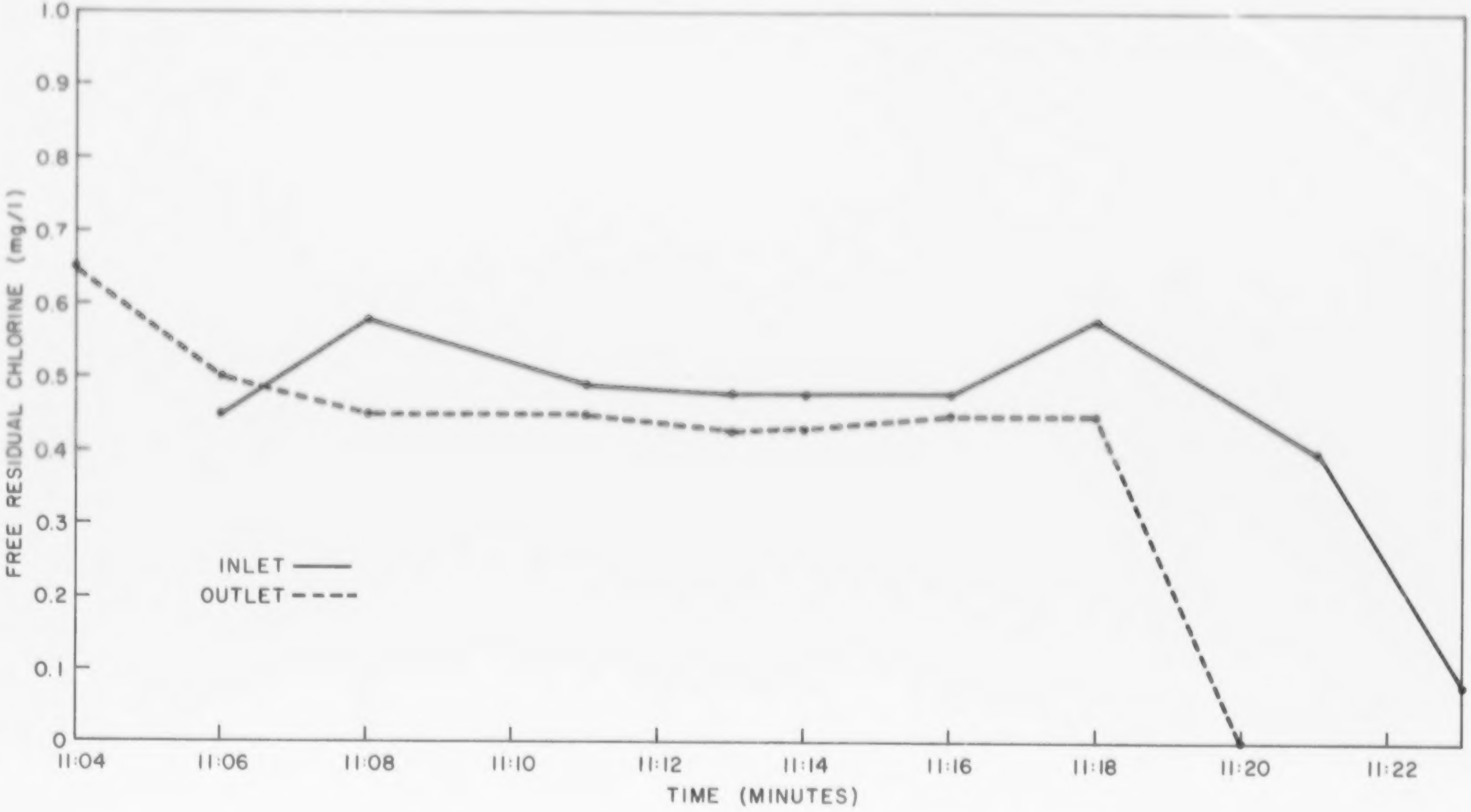
Water quality data for 1977.



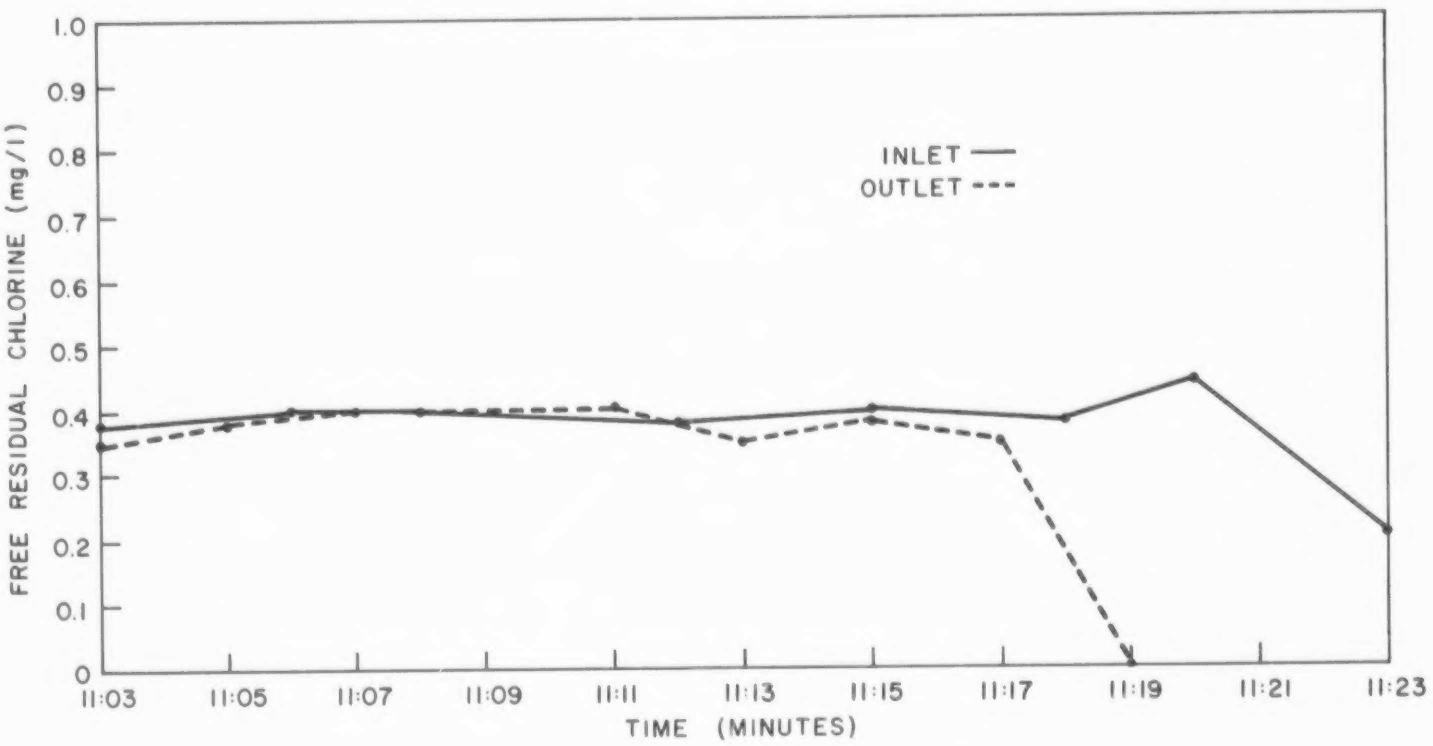
Water quality data for 1977.



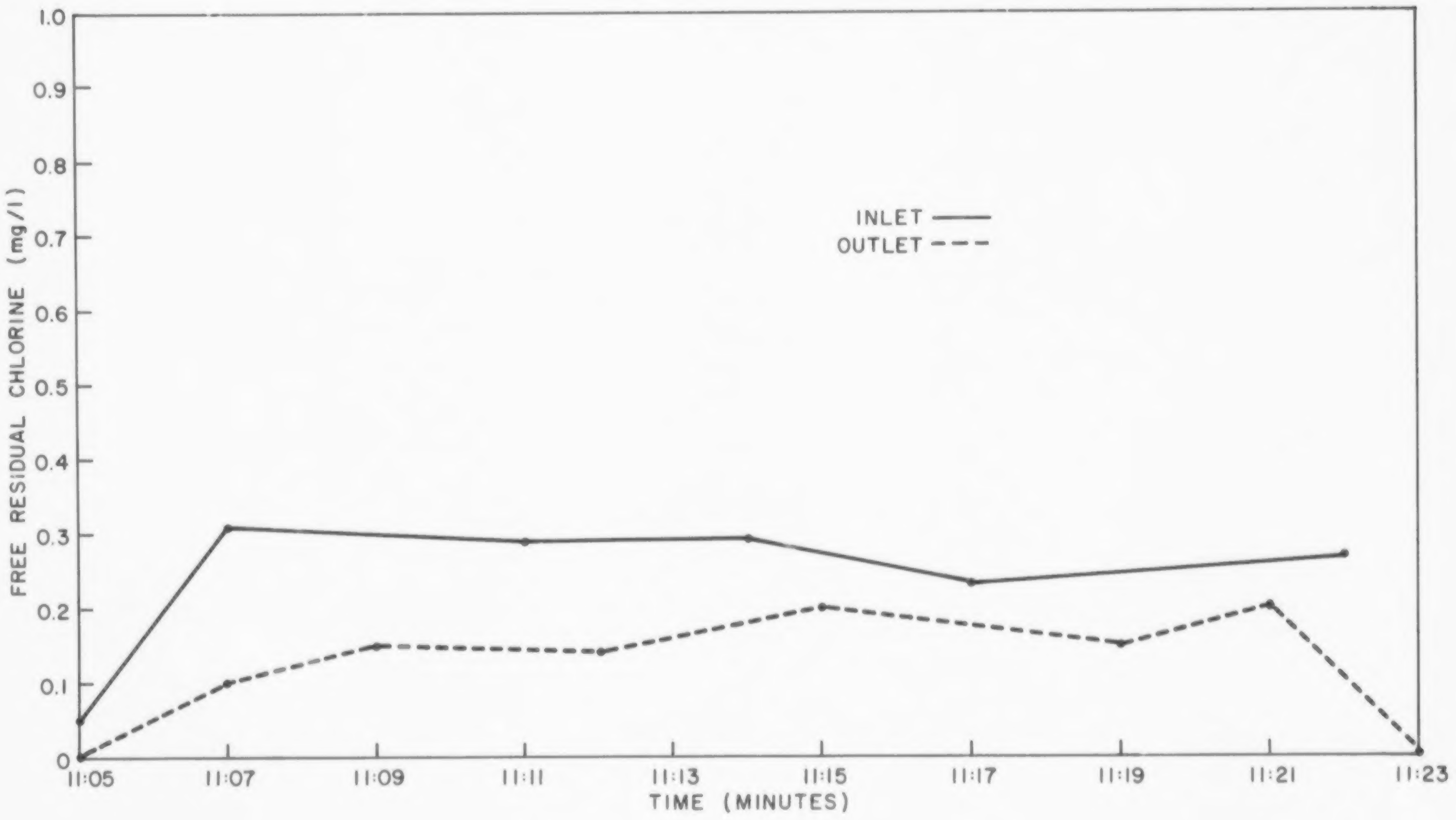
Unit 3 inlet vs. outlet free residual chlorine 1977.



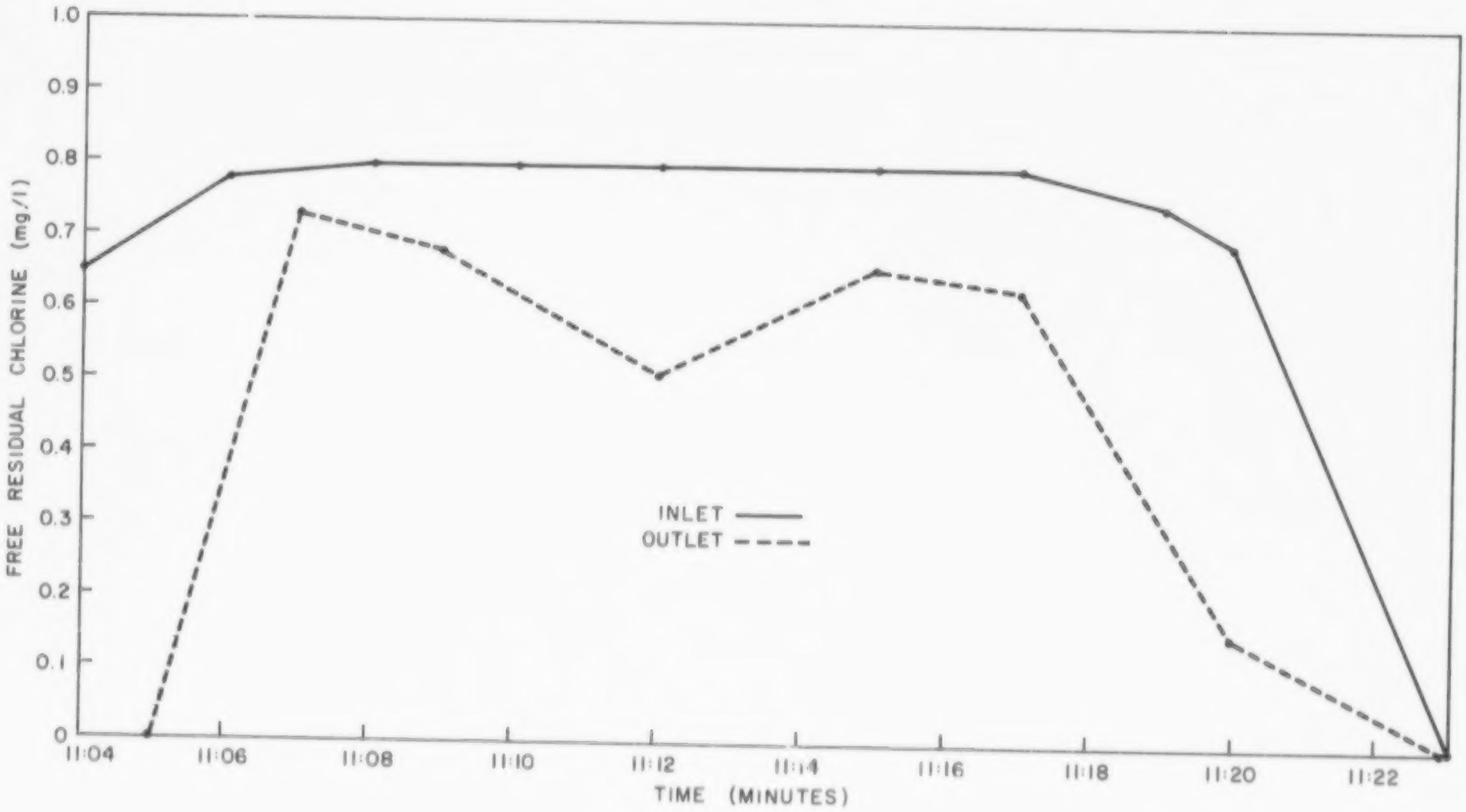
Unit 3 inlet vs. outlet free residual chlorine 9-9-77.



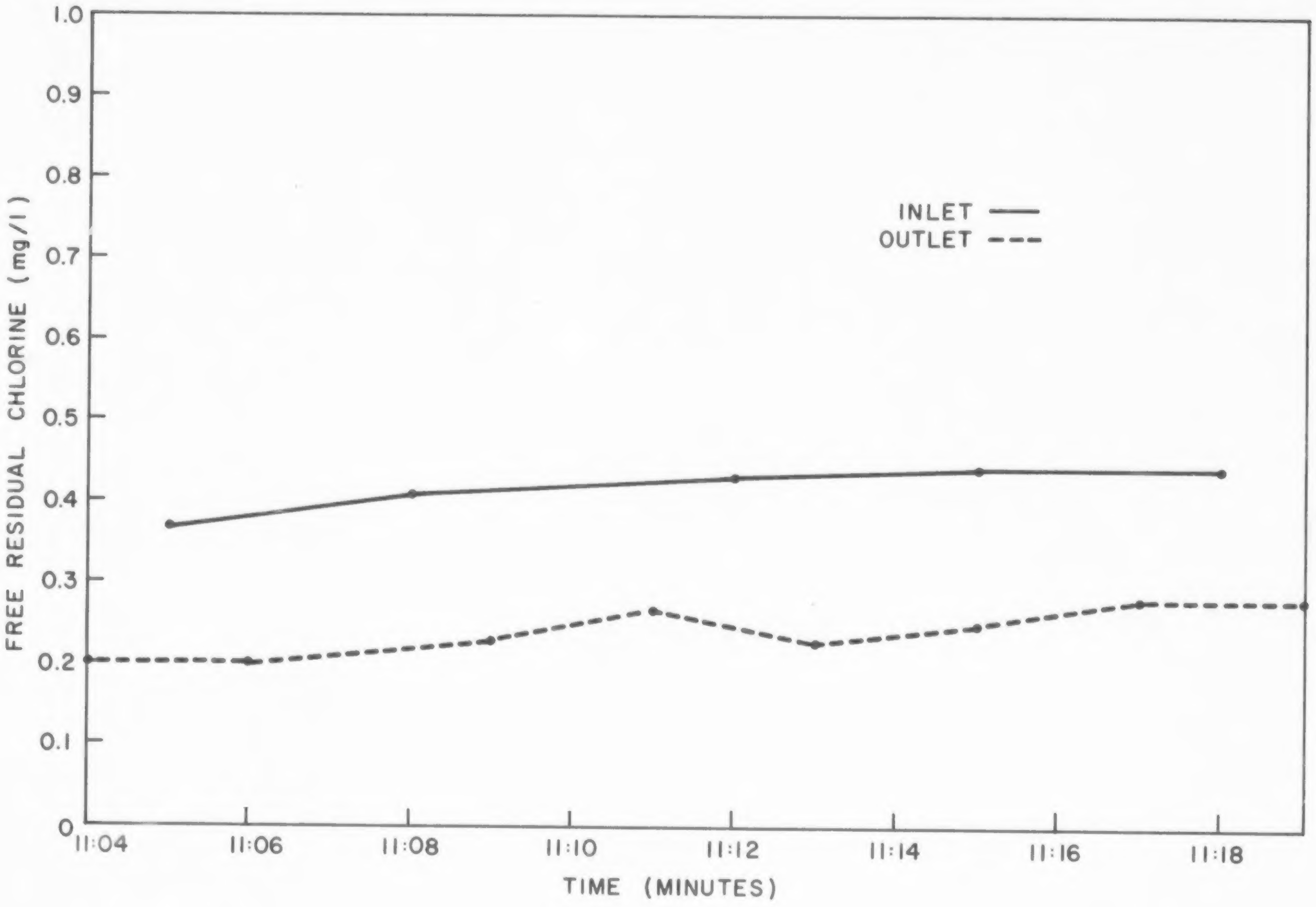
Unit 3 inlet vs. outlet free residual chlorine 9-16-77.



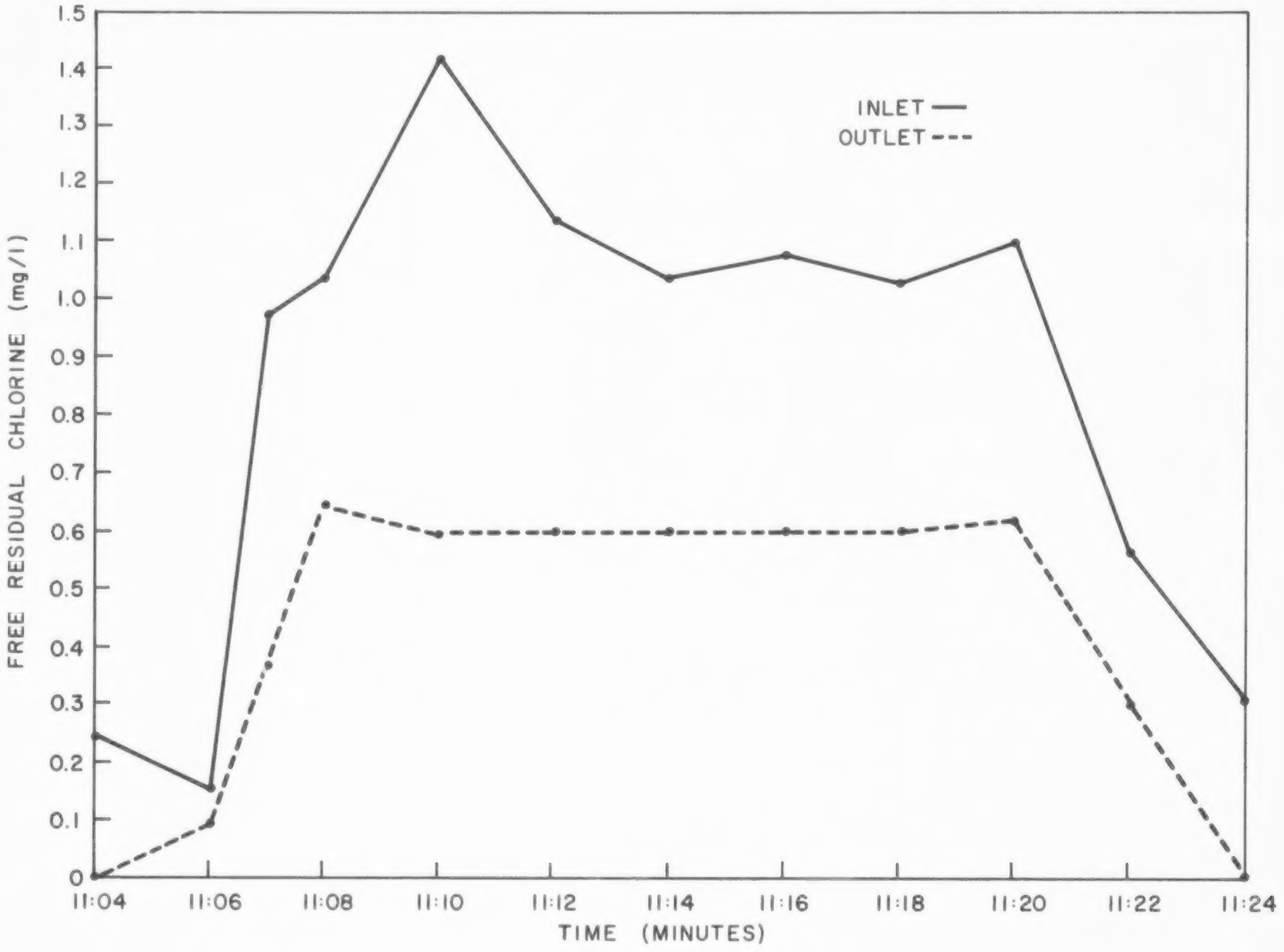
Unit 3 inlet vs. outlet free residual chlorine 6-3-77.



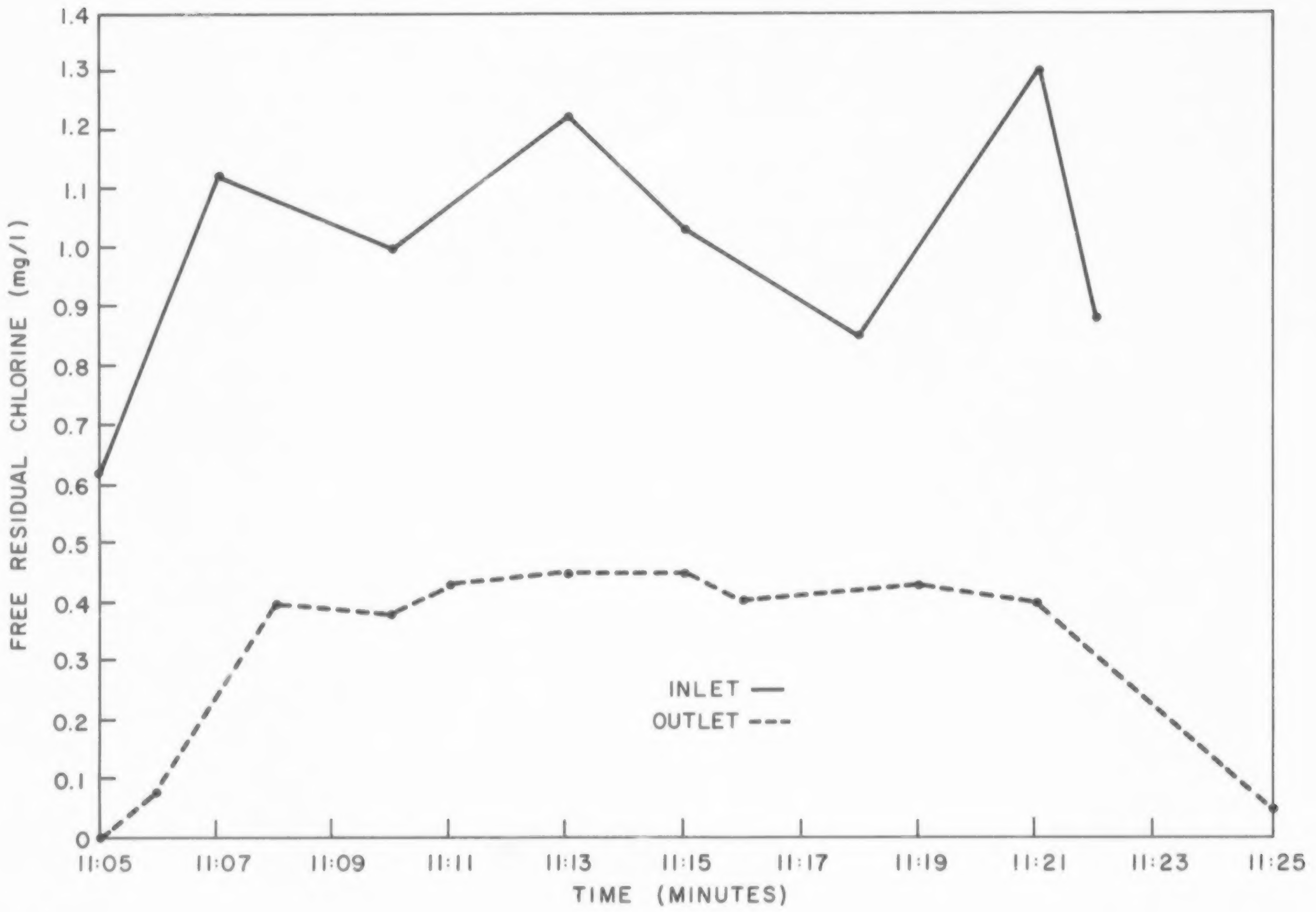
Unit 3 inlet vs. outlet free residual chlorine 6-10-77.



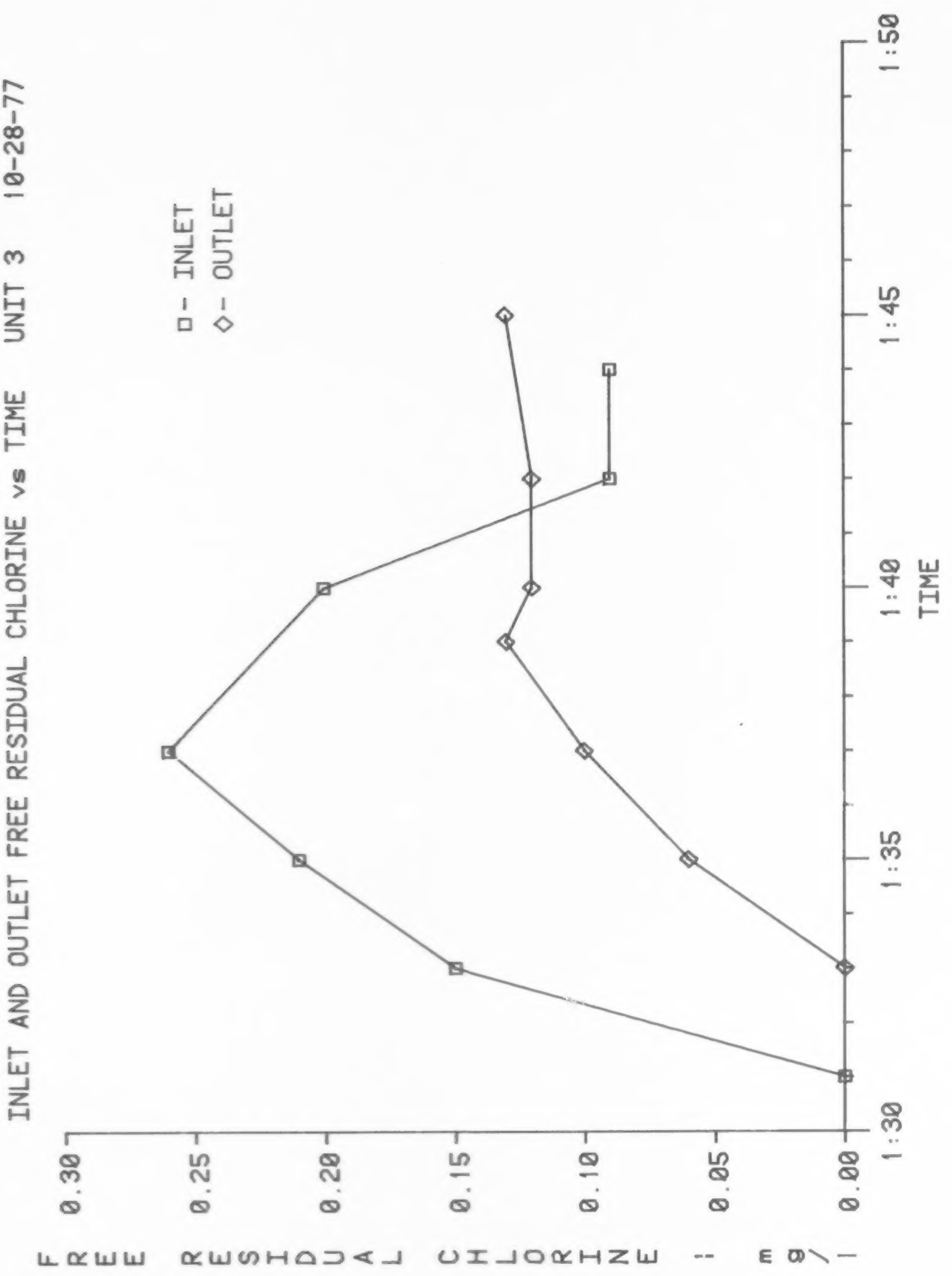
Unit 3 inlet vs. outlet free residual chlorine 9-30-77.



Unit 3 inlet vs. outlet free residual chlorine 6-30-77.

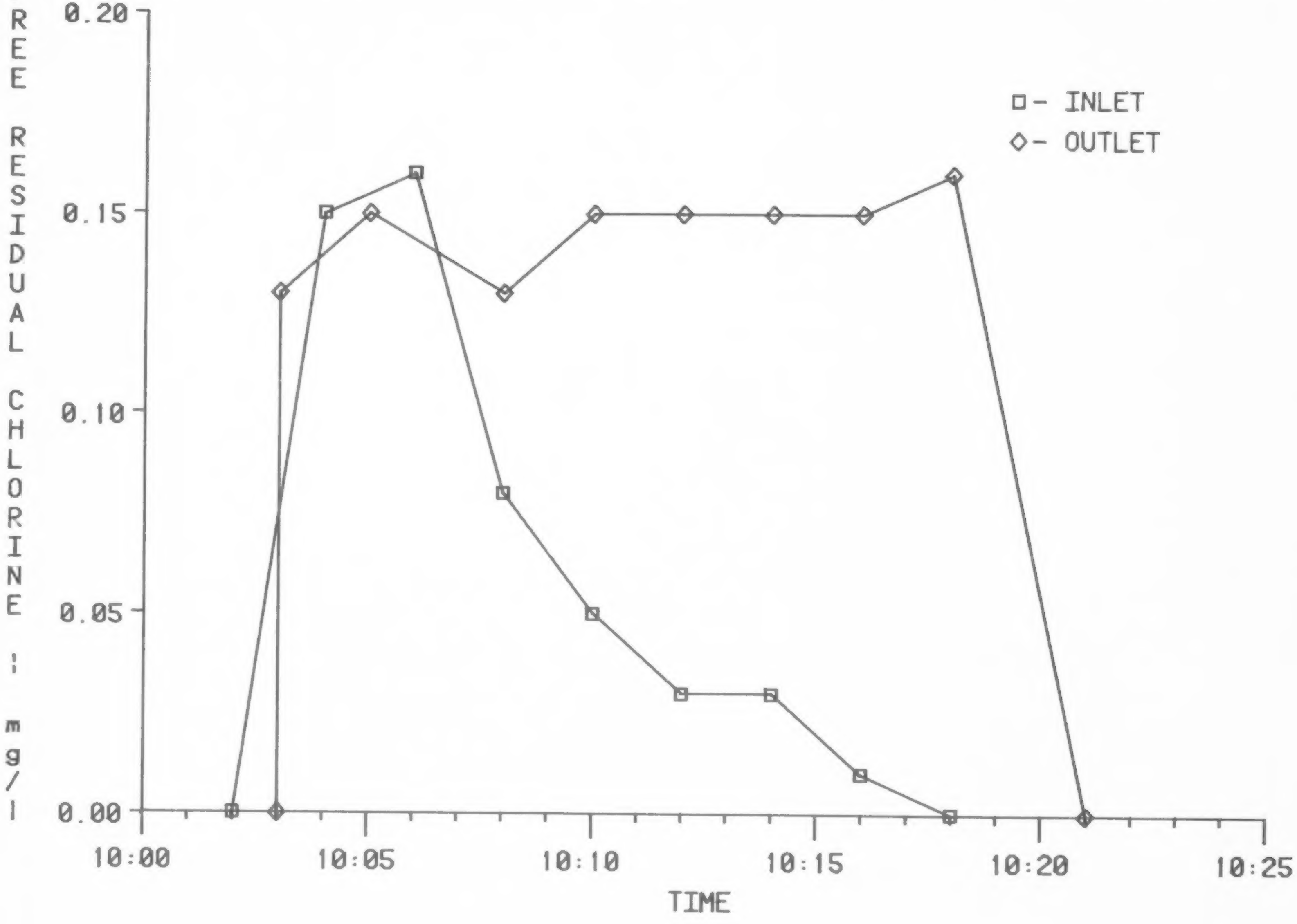


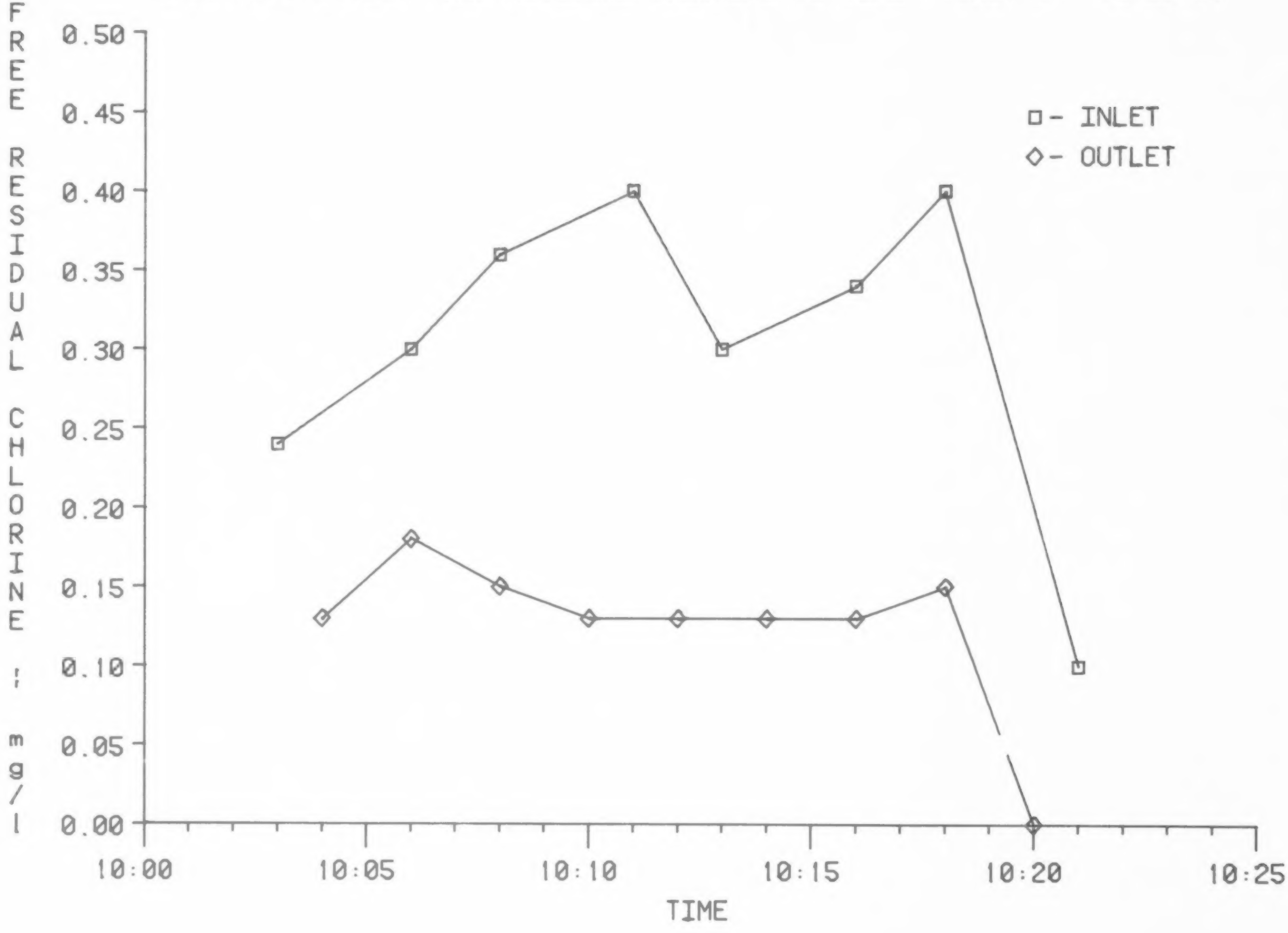
Unit 3 inlet vs. outlet free residual chlorine 7-6-77.



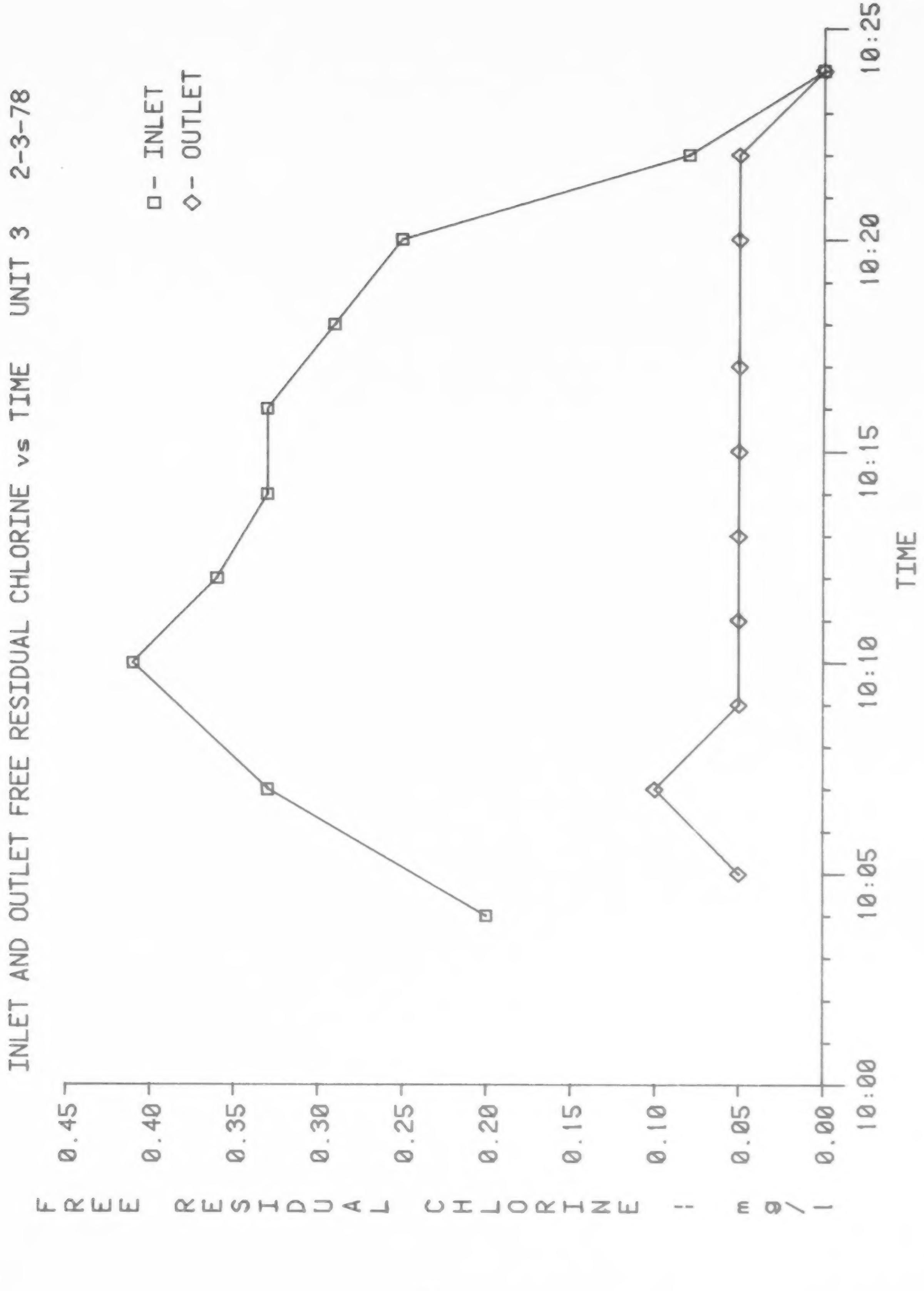
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 10-28-77

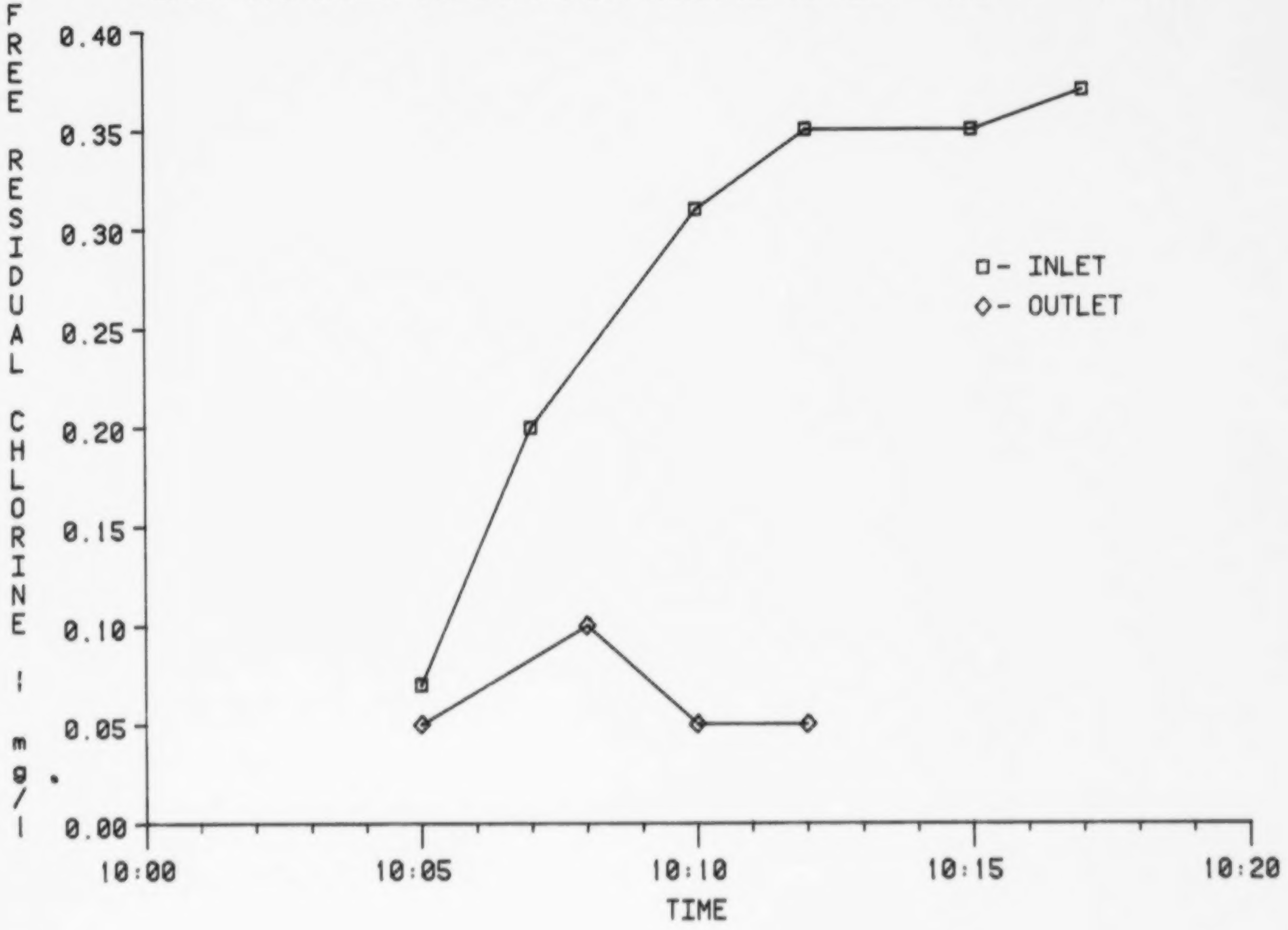
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 11-18-77



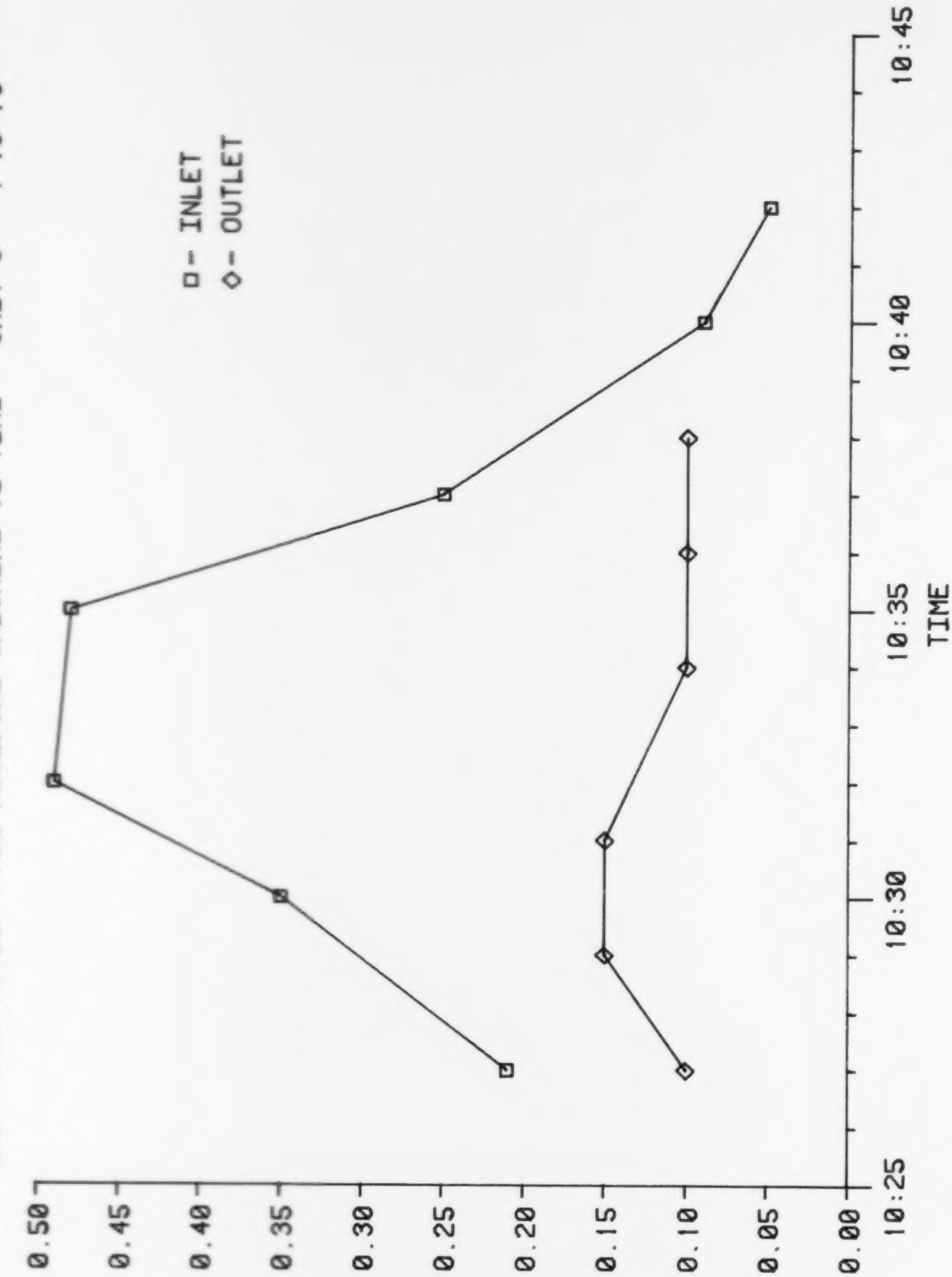


INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME   UNIT 3   12-22-77

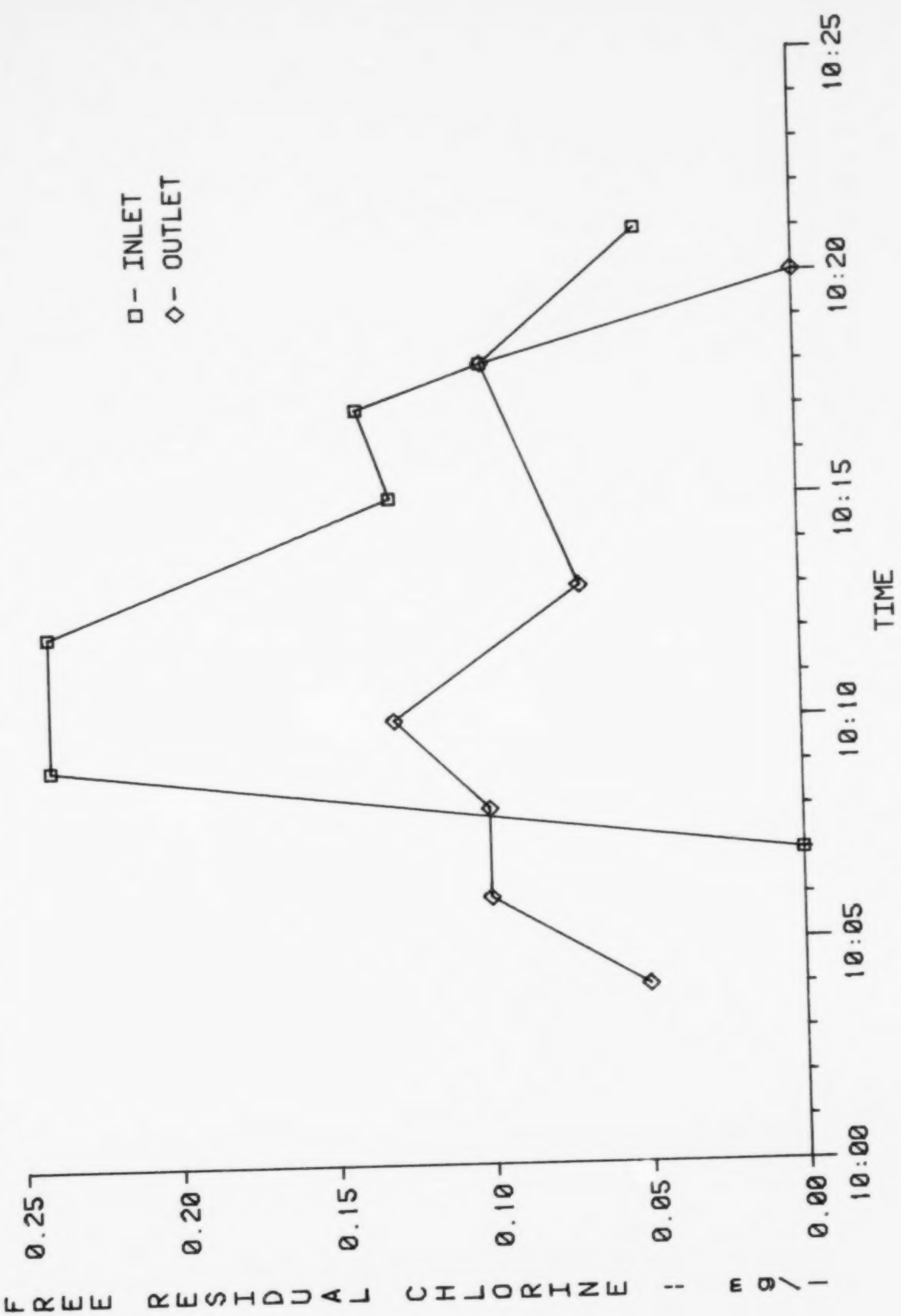

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 2-3-78
□ - INLET
◇ - OUTLET
FREE RESIDUAL CHLORINE - mg/l
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
10:00
10:05
10:10
10:15
10:20
10:25
TIME

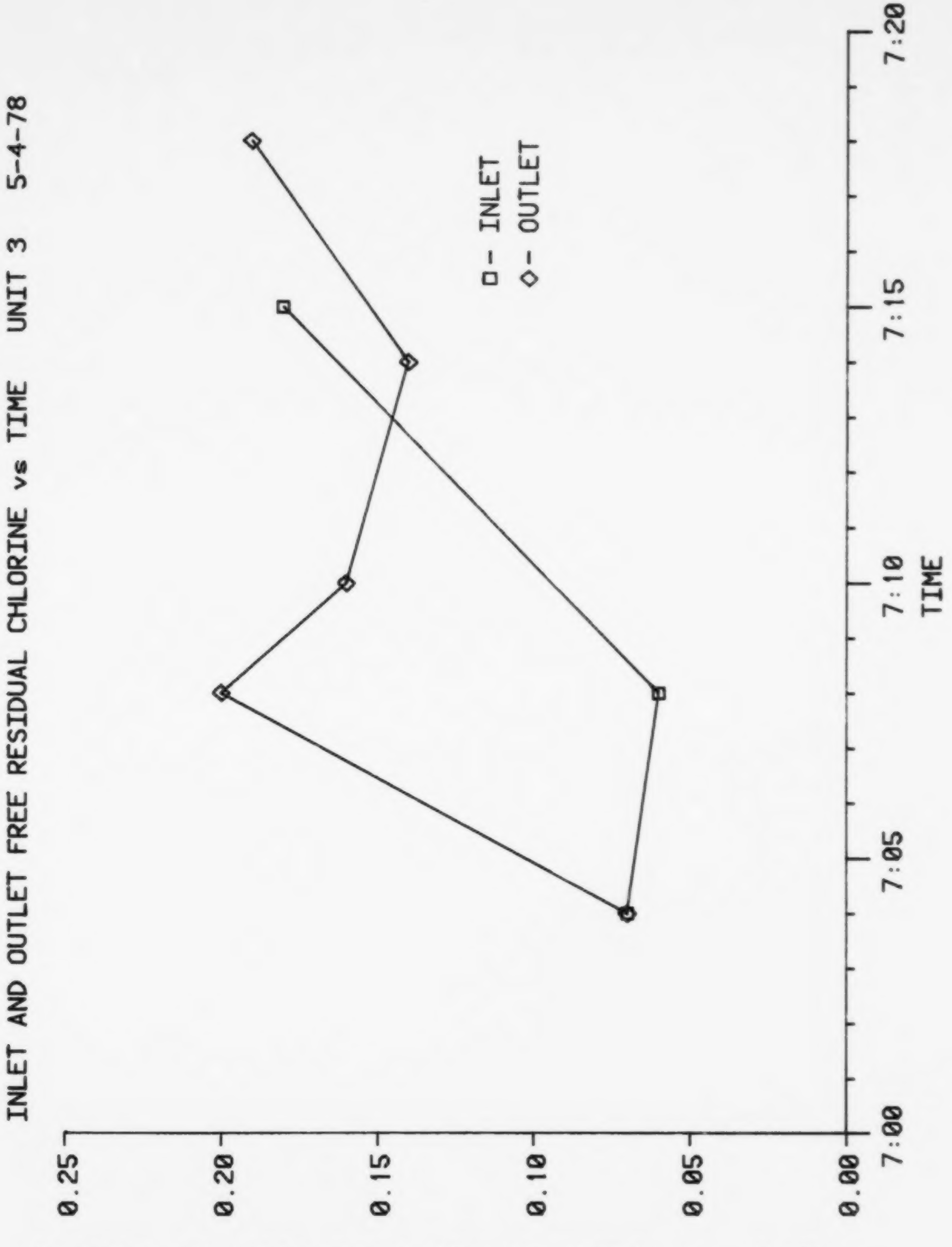


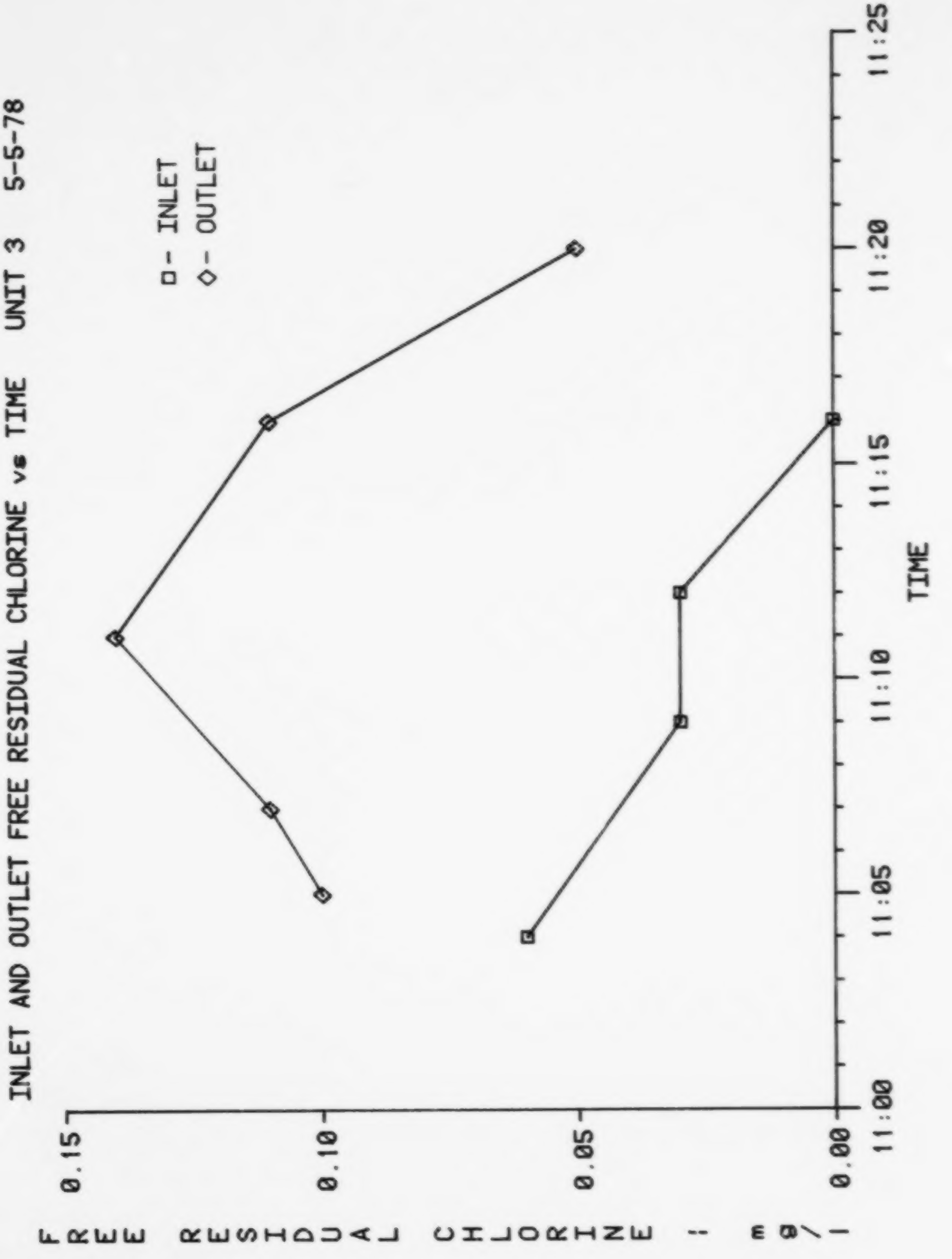
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 4-13-78



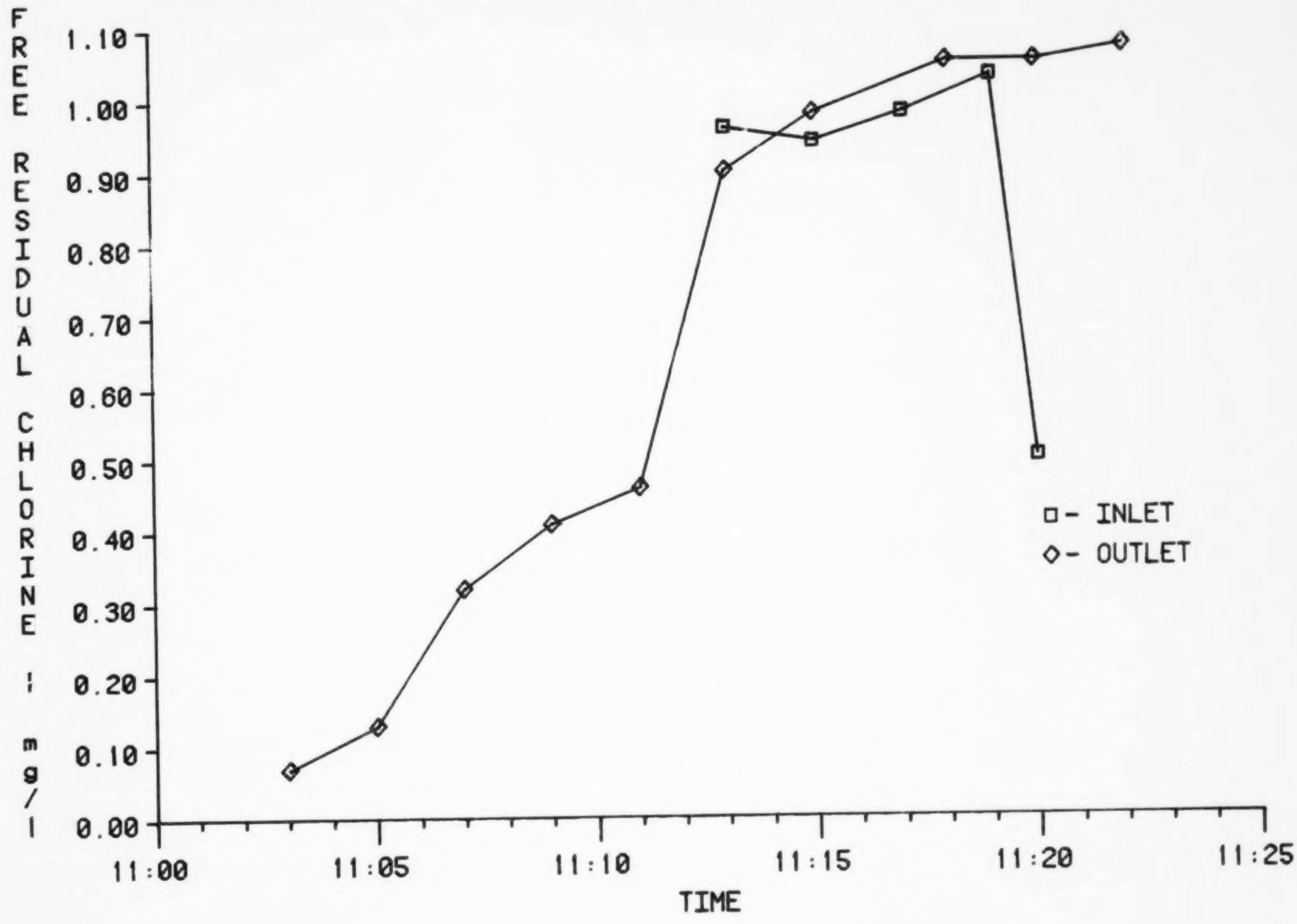
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 4-28-78



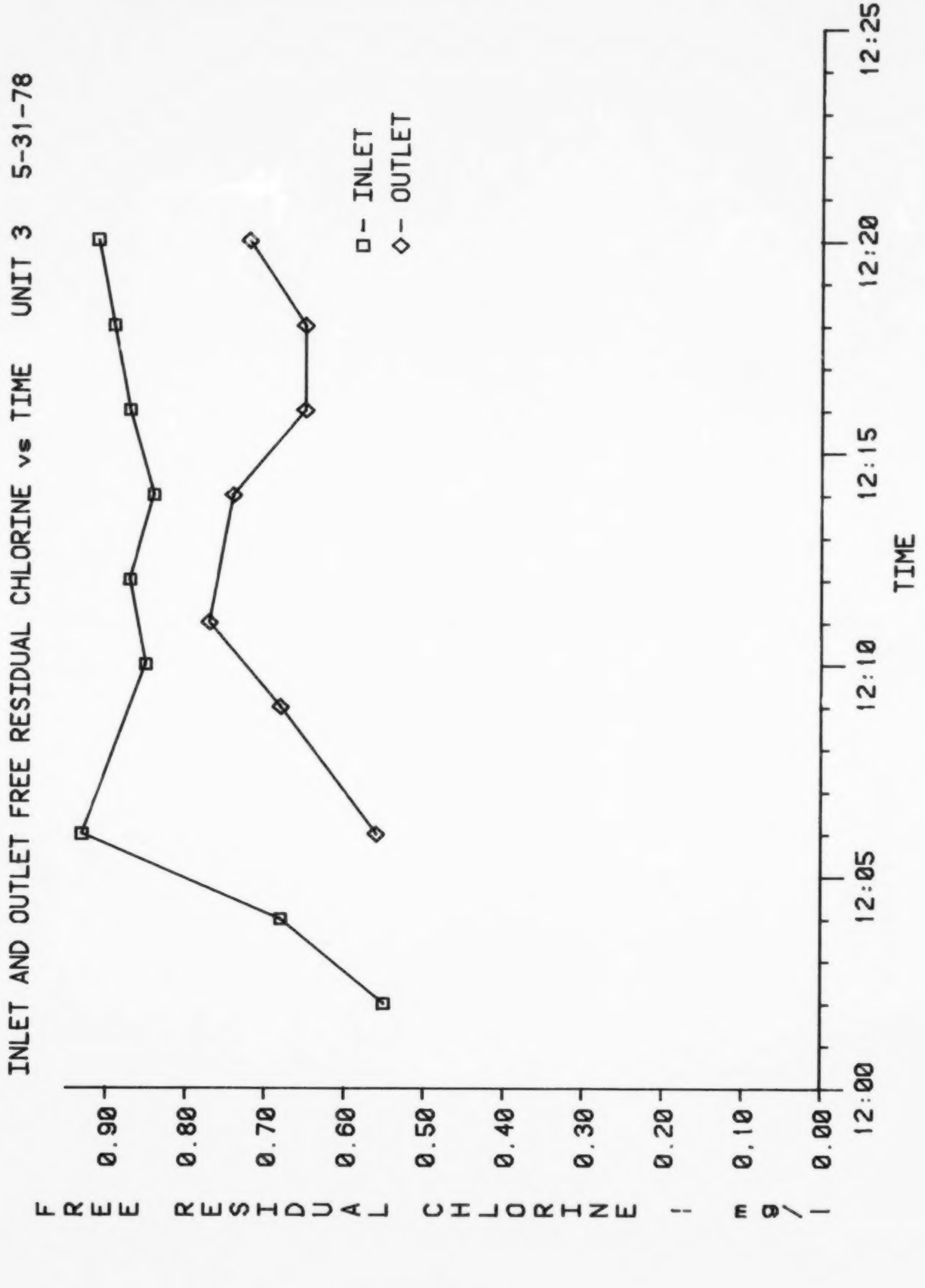

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 5-4-78
FREE RESIDUAL CHLORINE : mg/l
0.25
0.20
0.15
0.10
0.05
0.00
7:00
7:05
7:10
7:15
7:20
TIME
□- INLET
◇- OUTLET



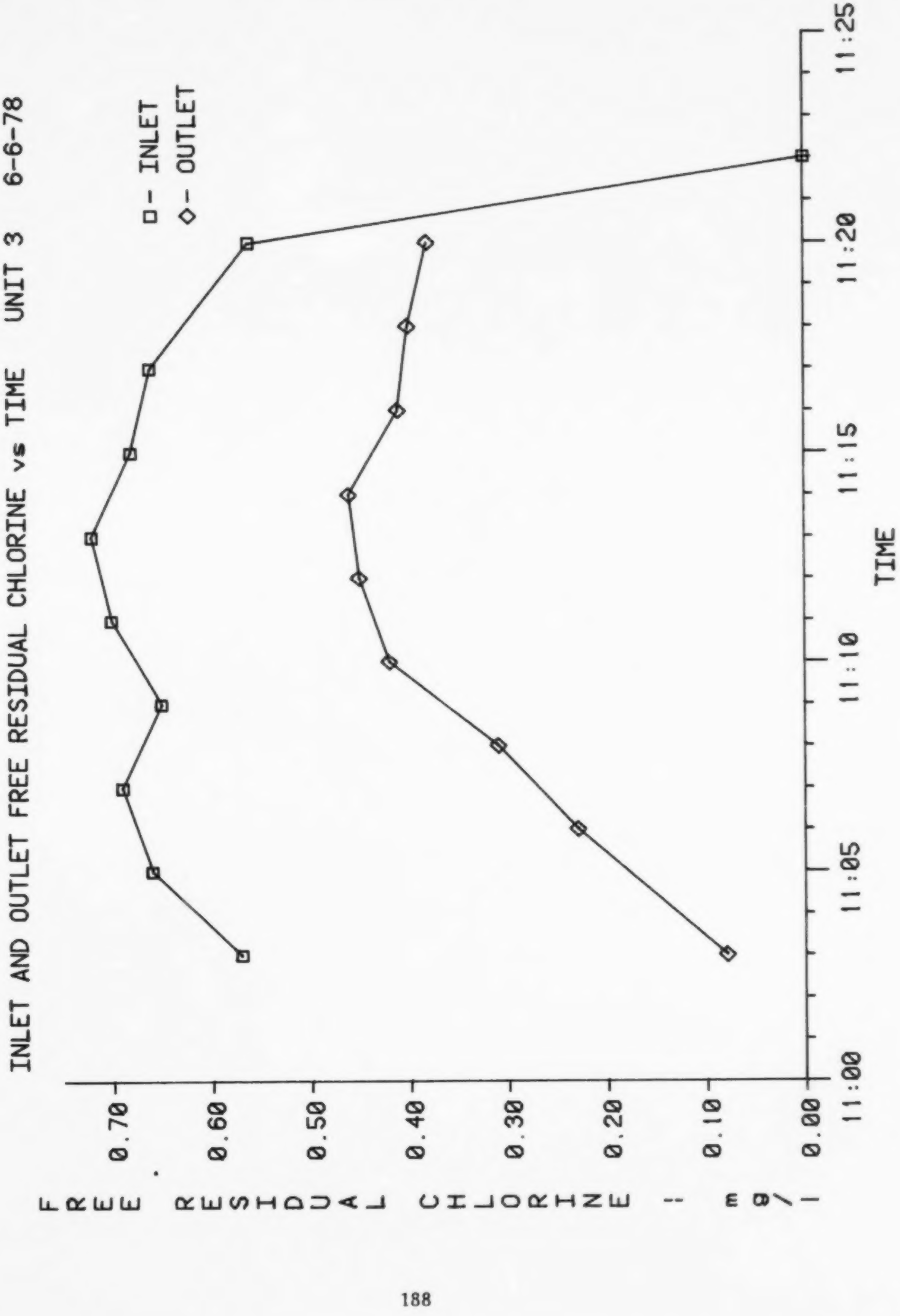
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 5-5-78



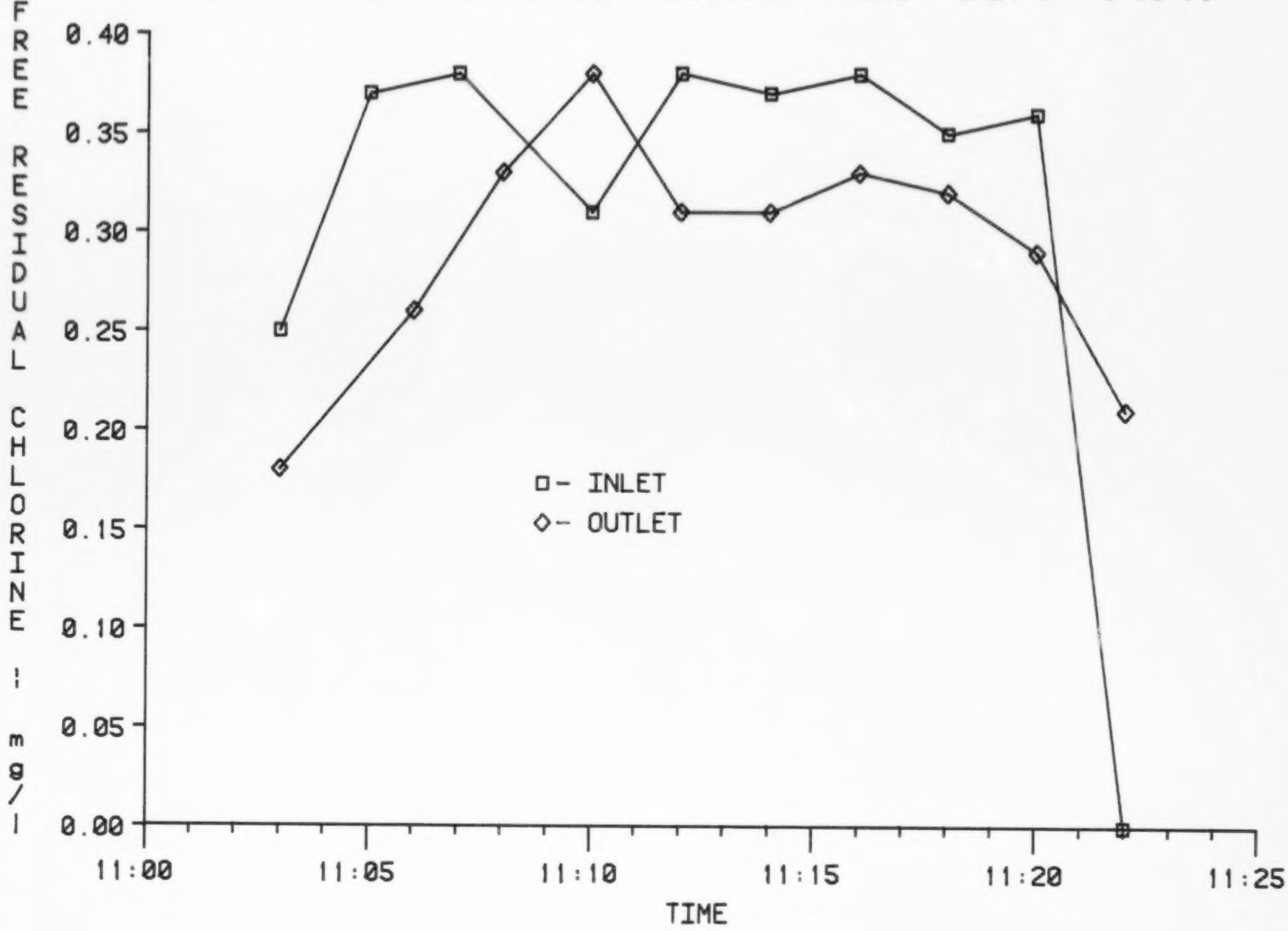
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME   UNIT 3   5-16-78



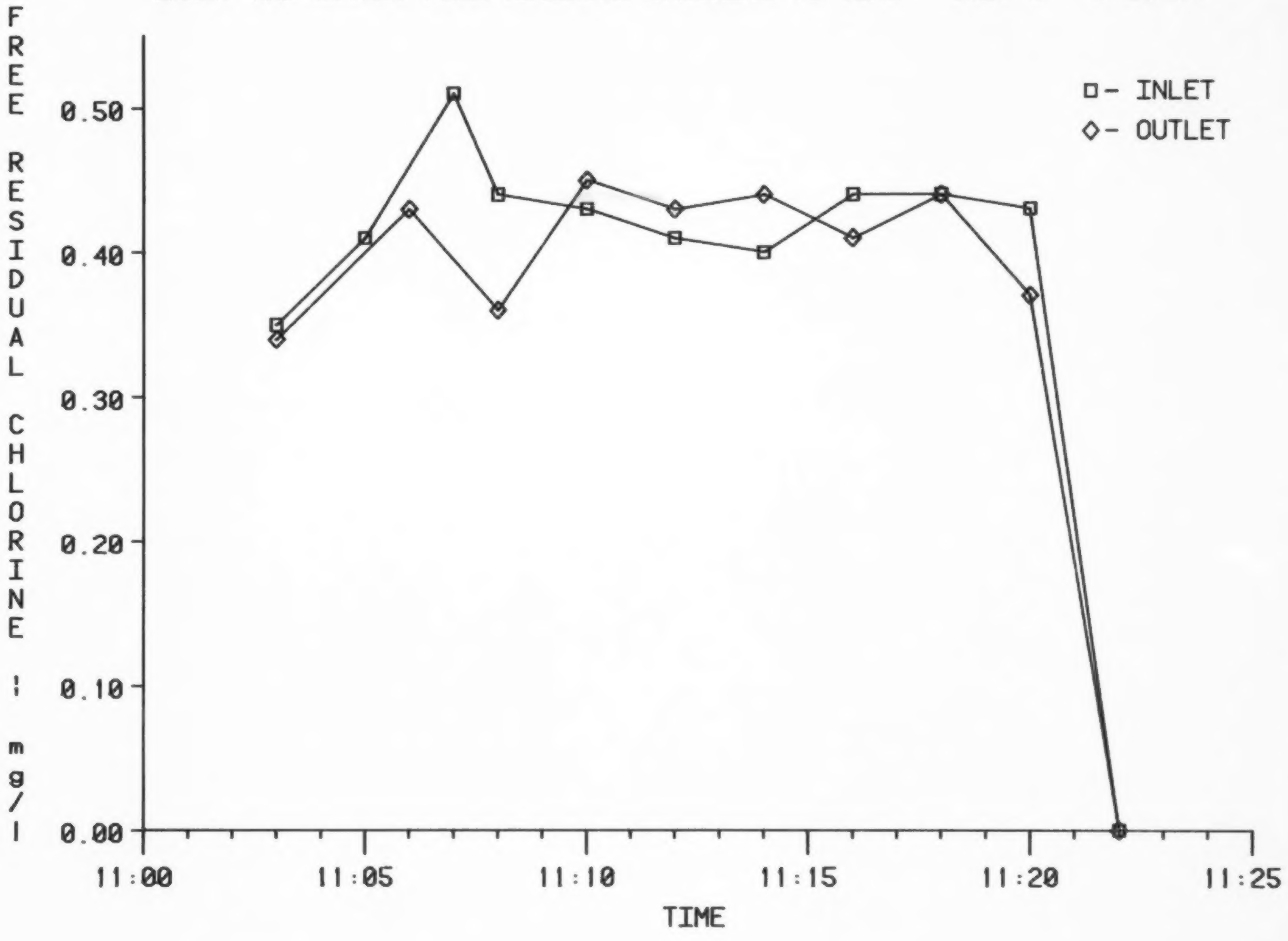
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 5-31-78

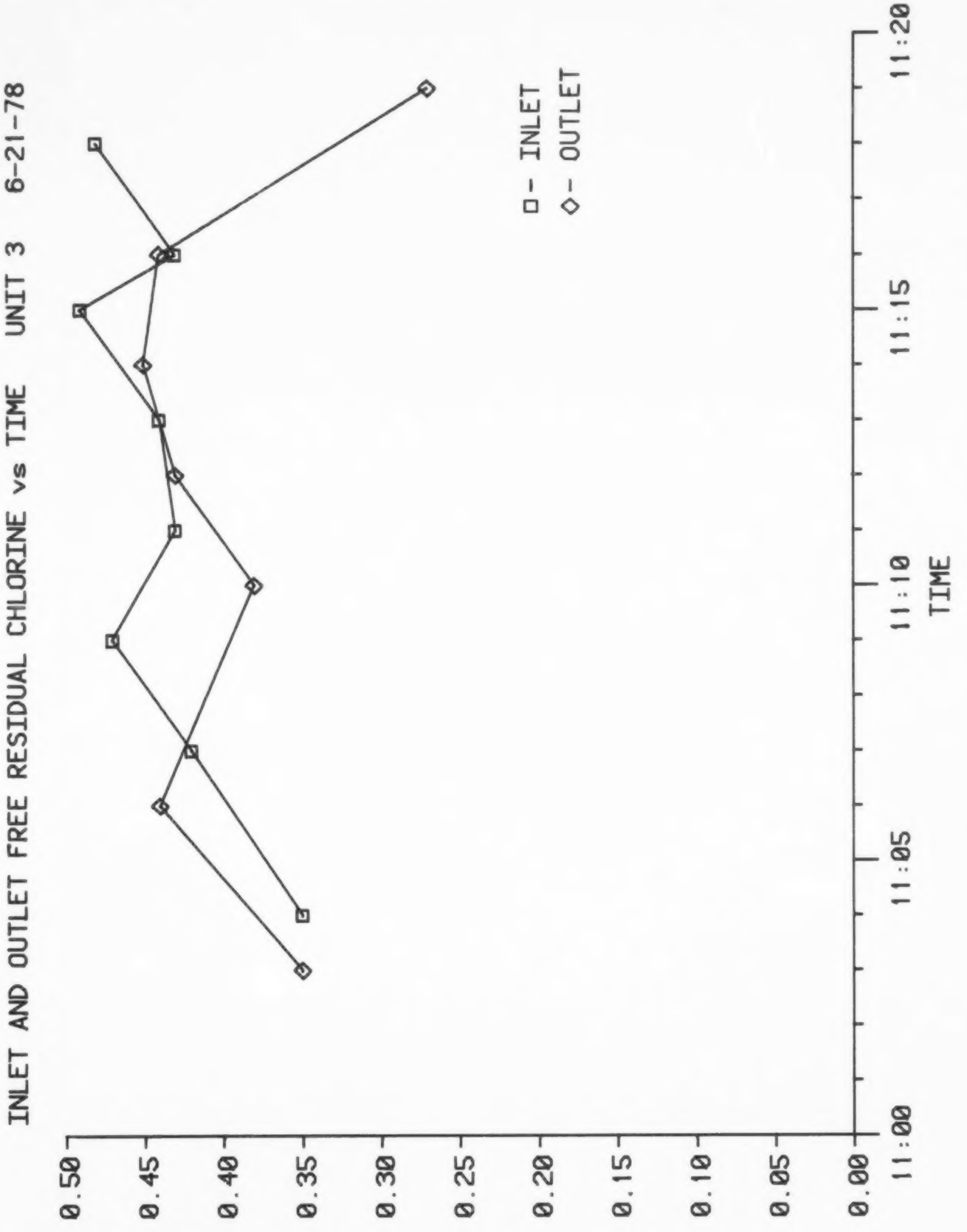

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 6-6-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE - mg/l
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
TIME
11:00
11:05
11:10
11:15
11:20
11:25

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 6-13-78

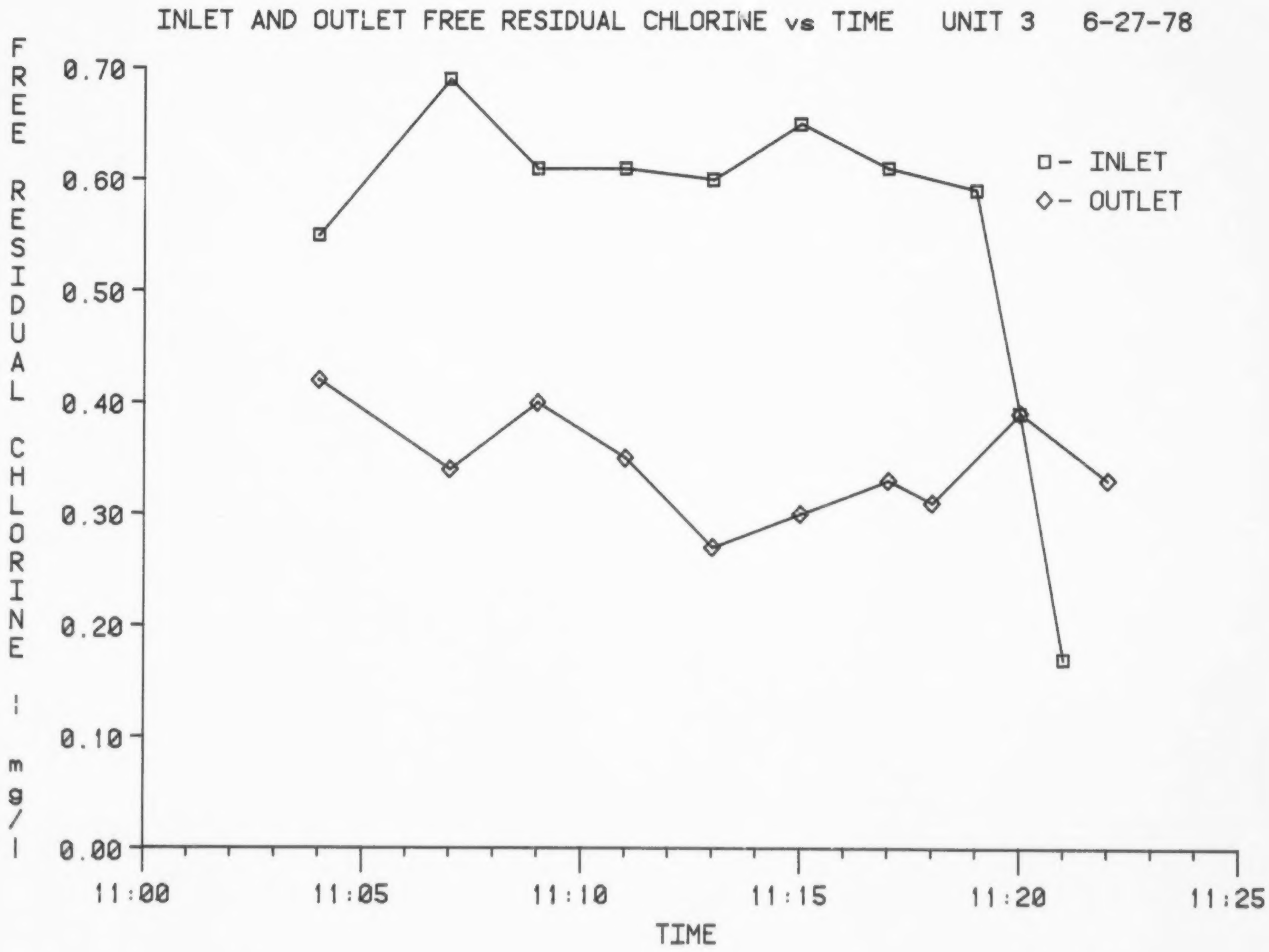


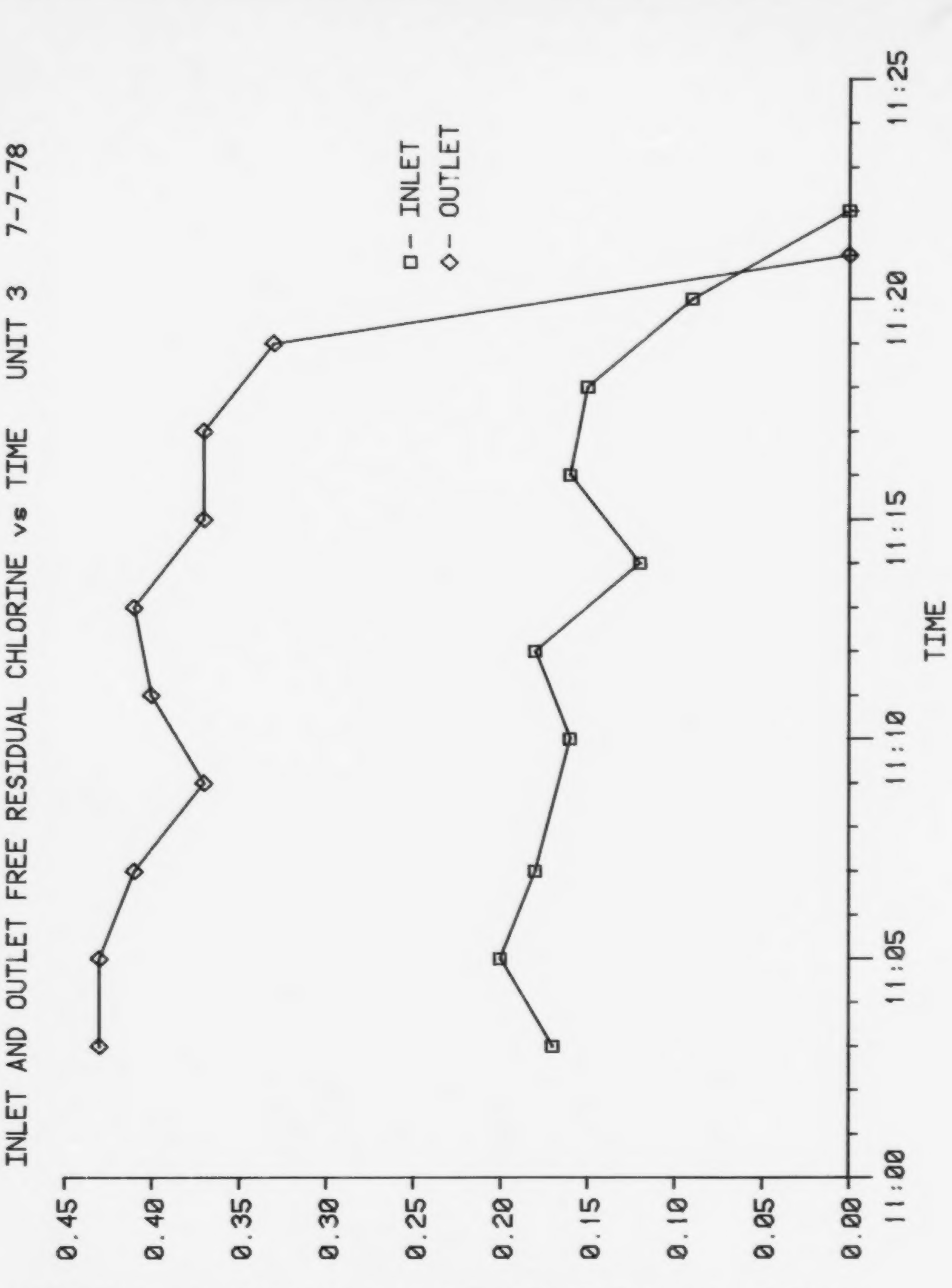
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 6-20-78



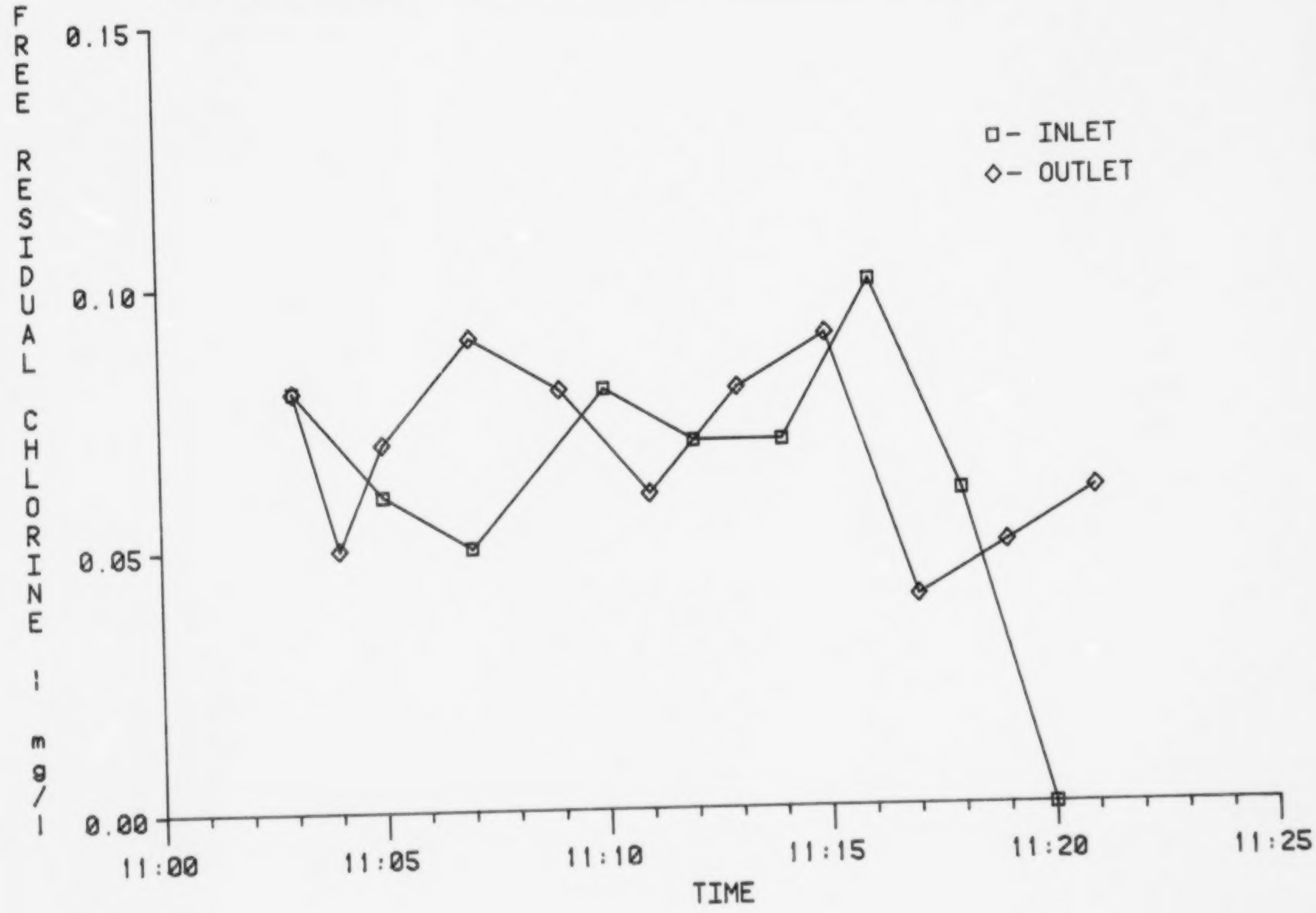


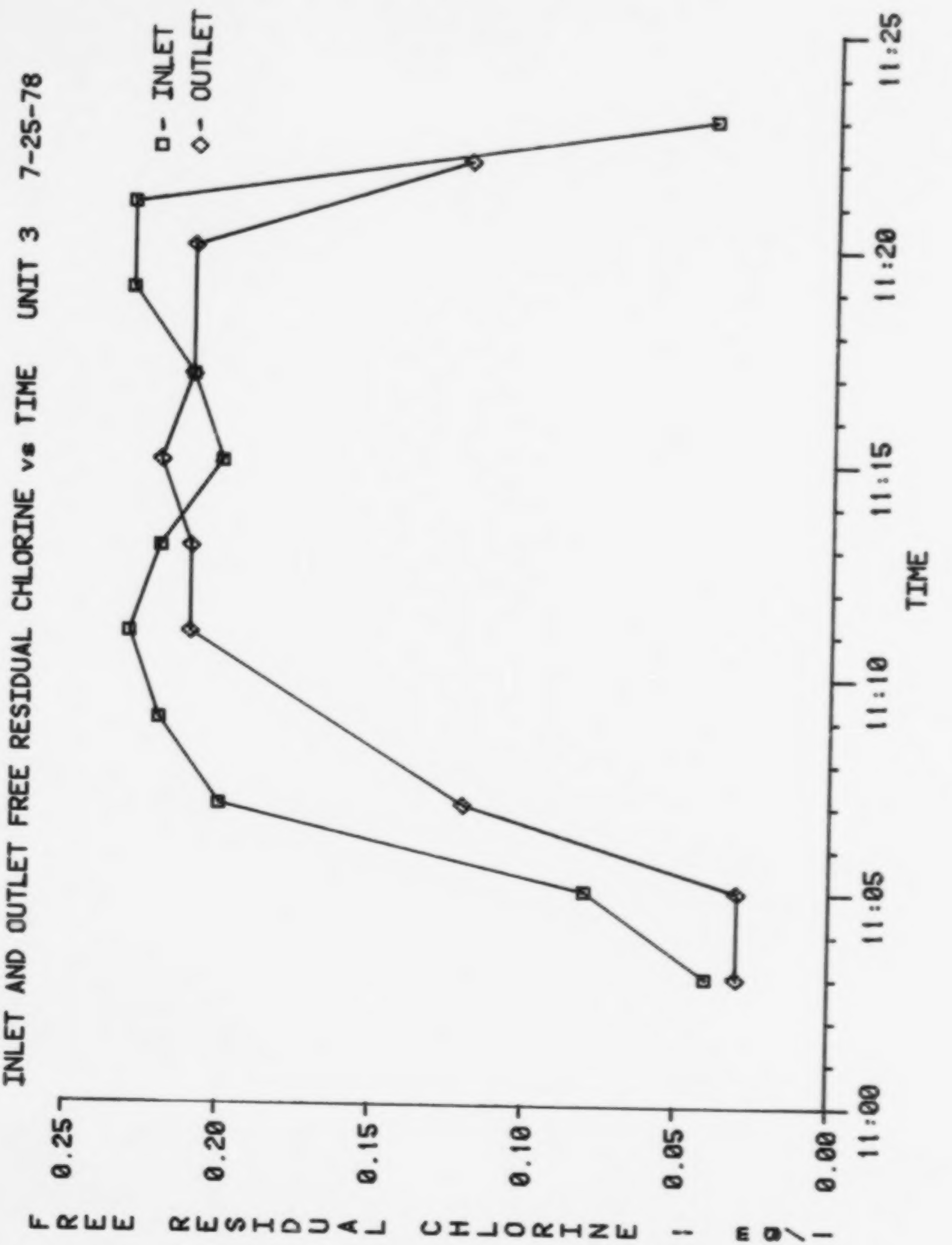
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 6-21-78


INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 6-27-78
FREE RESIDUAL CHLORINE -- mg/l
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
11:00
11:05
11:10
11:15
11:20
11:25
TIME
□- INLET
◇- OUTLET


INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 7-7-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE - mg/l
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
11:00
11:05
11:10
11:15
11:20
11:25
TIME

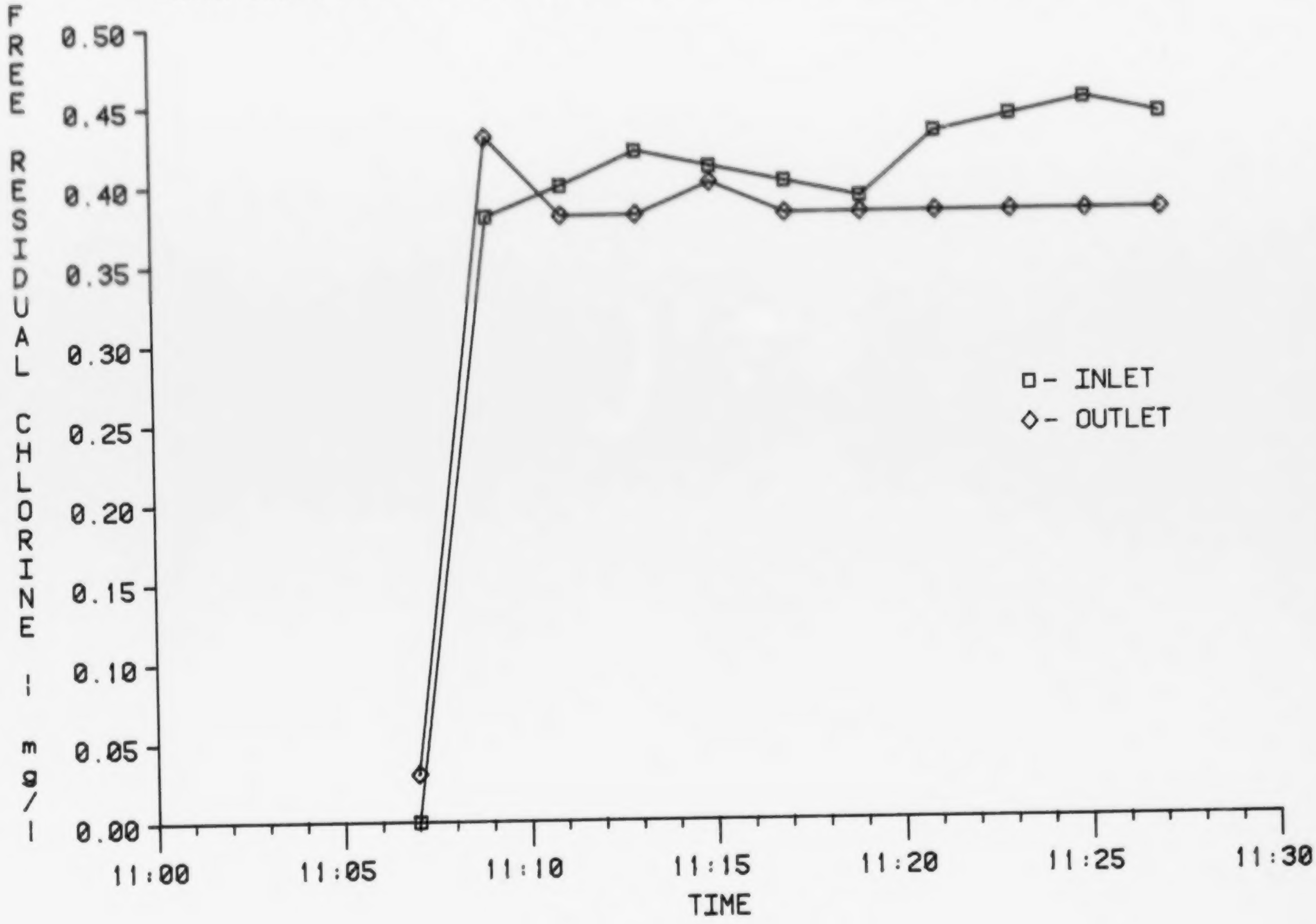
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 7-18-78

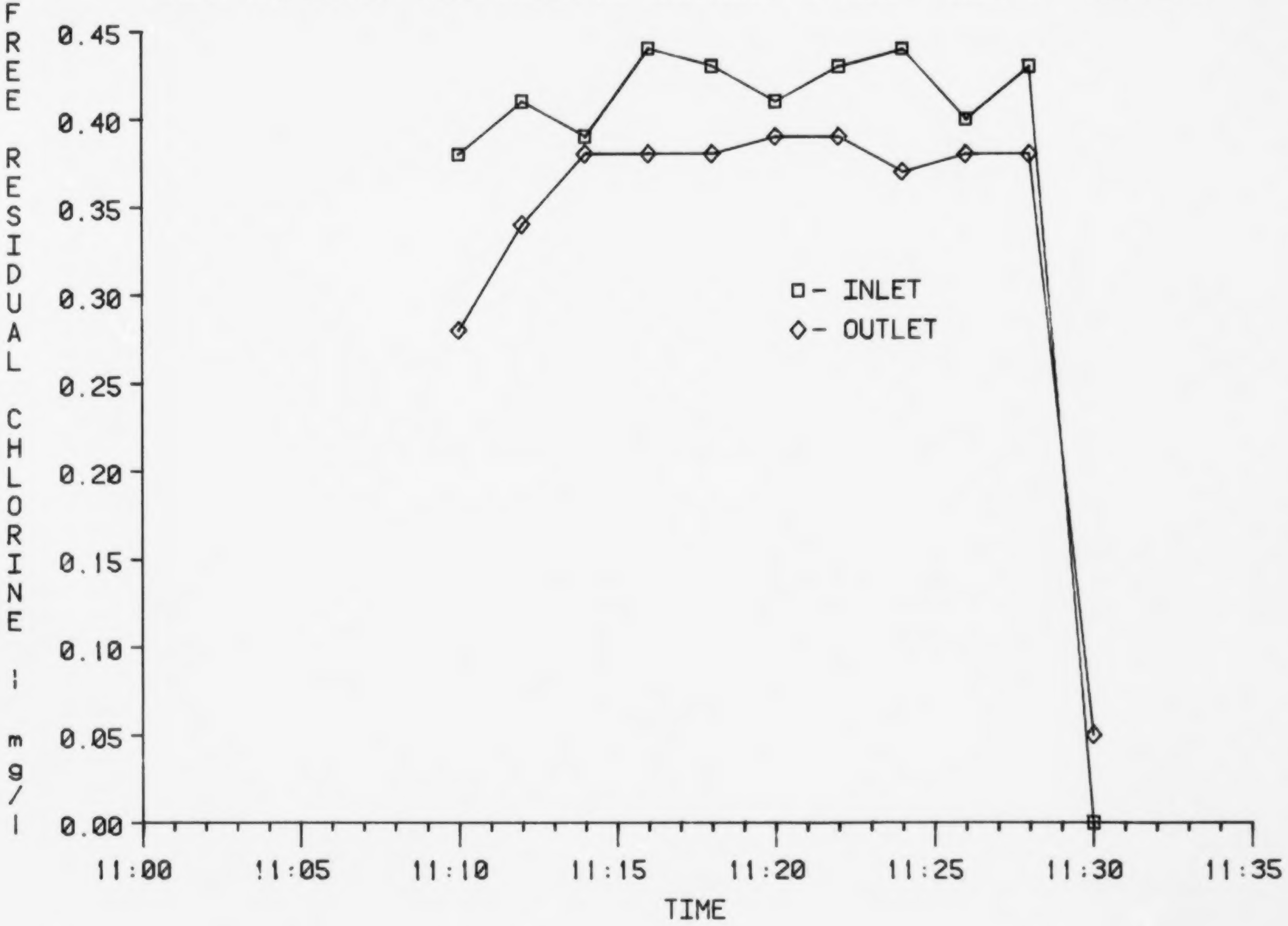




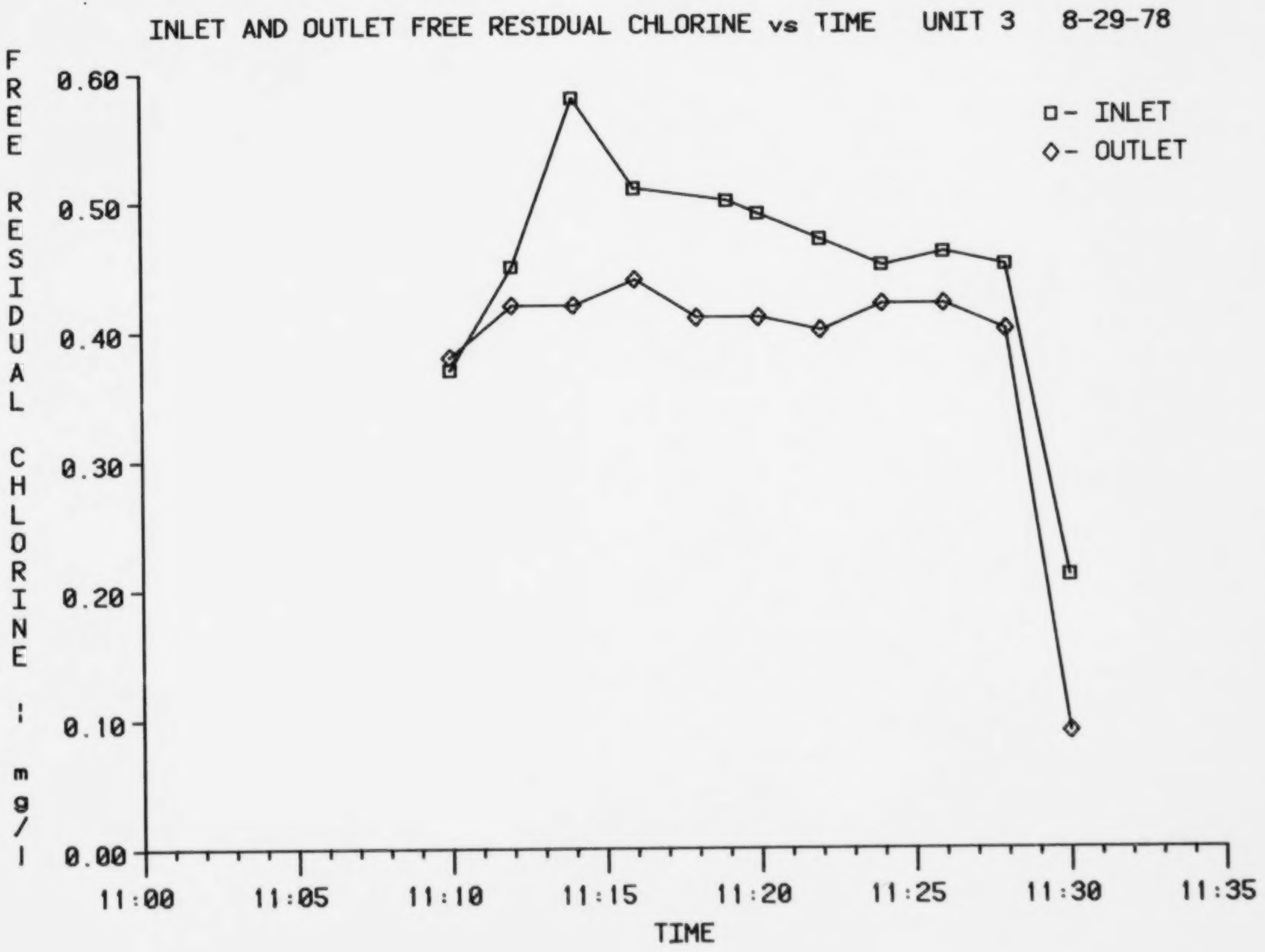
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 7-25-78

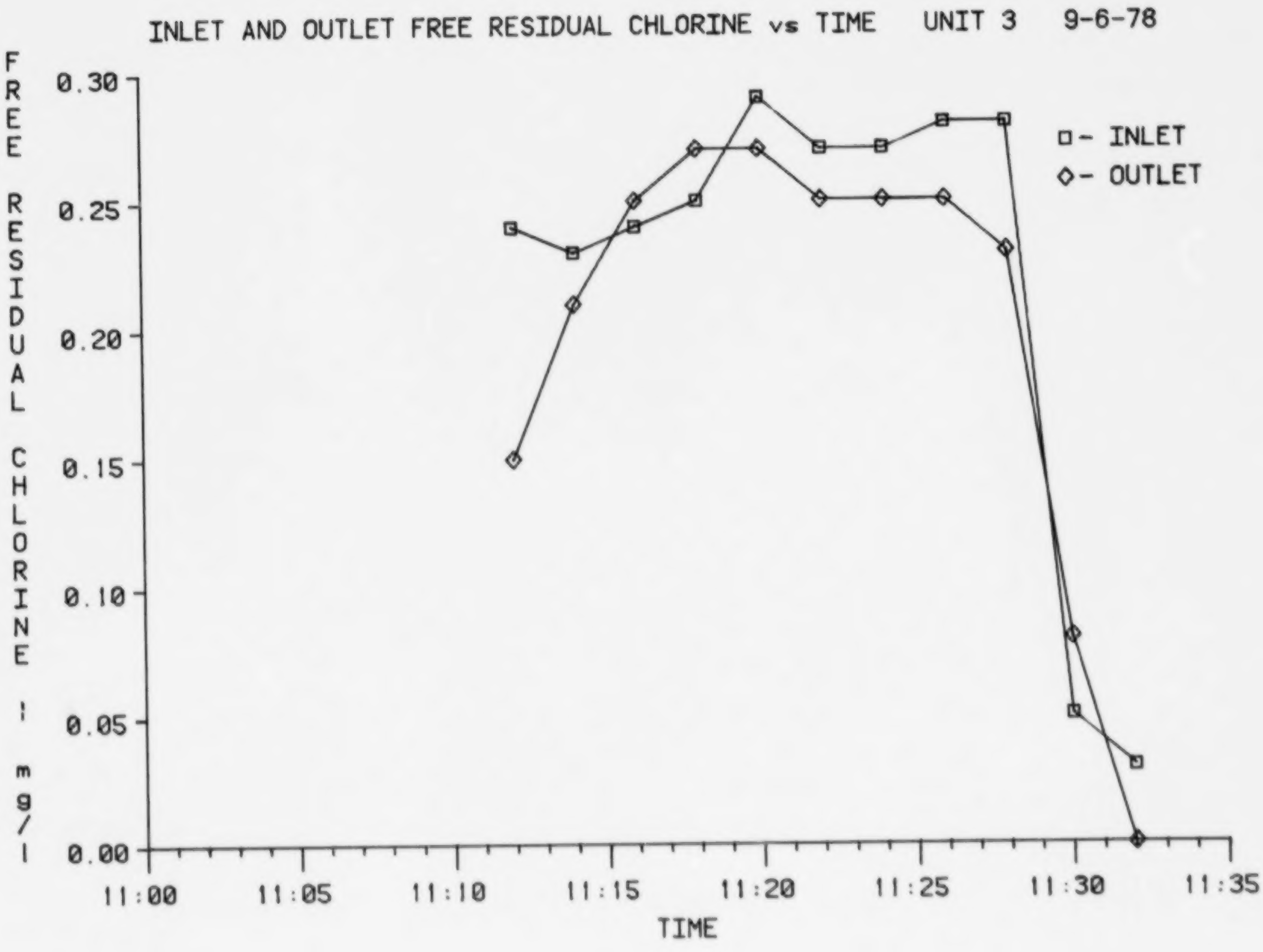
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME   UNIT 3   8-2-78



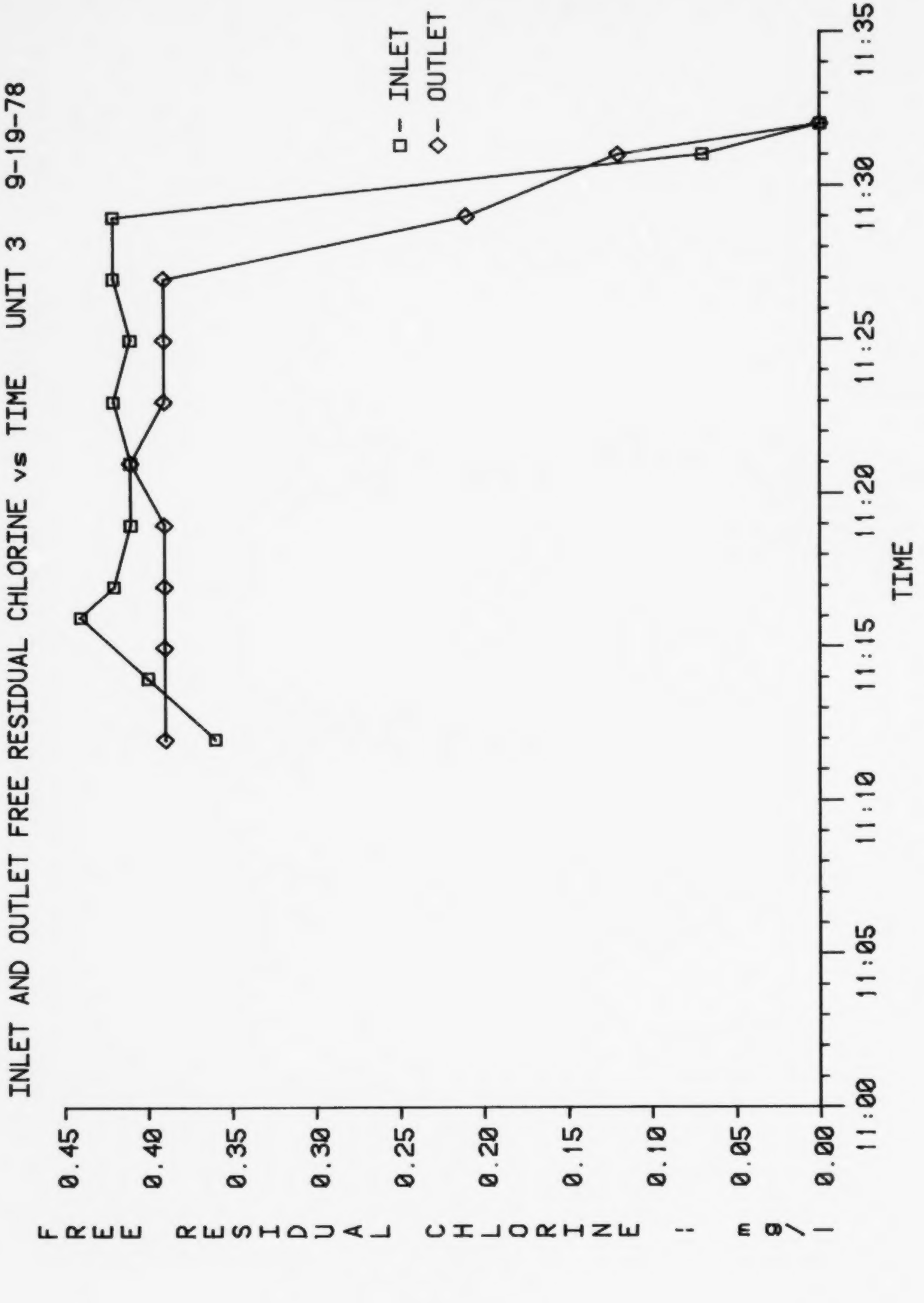


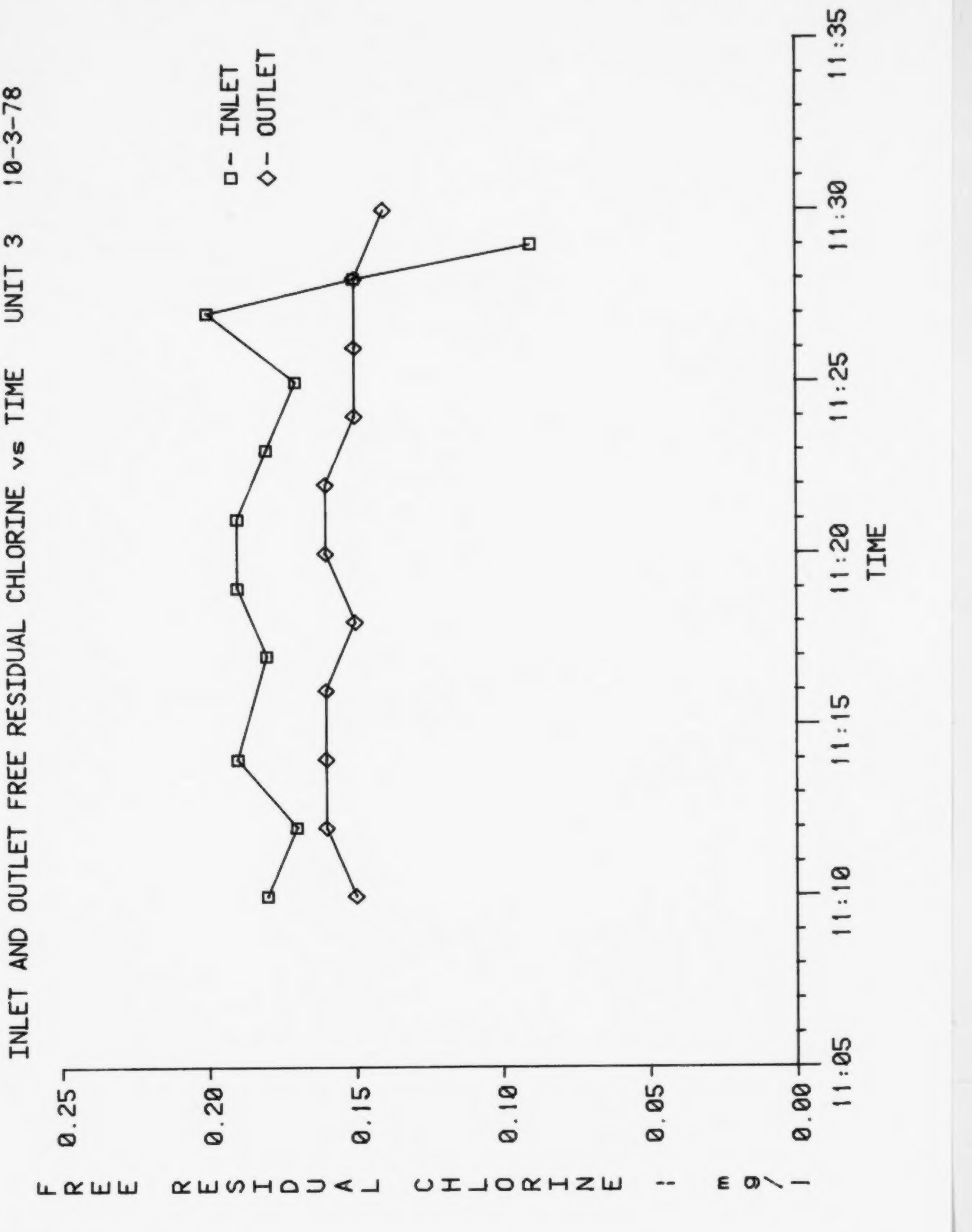
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 8-15-78


INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 8-29-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE : mg/l
0.60
0.50
0.40
0.30
0.20
0.10
0.00
11:00
11:05
11:10
11:15
11:20
11:25
11:30
11:35
TIME

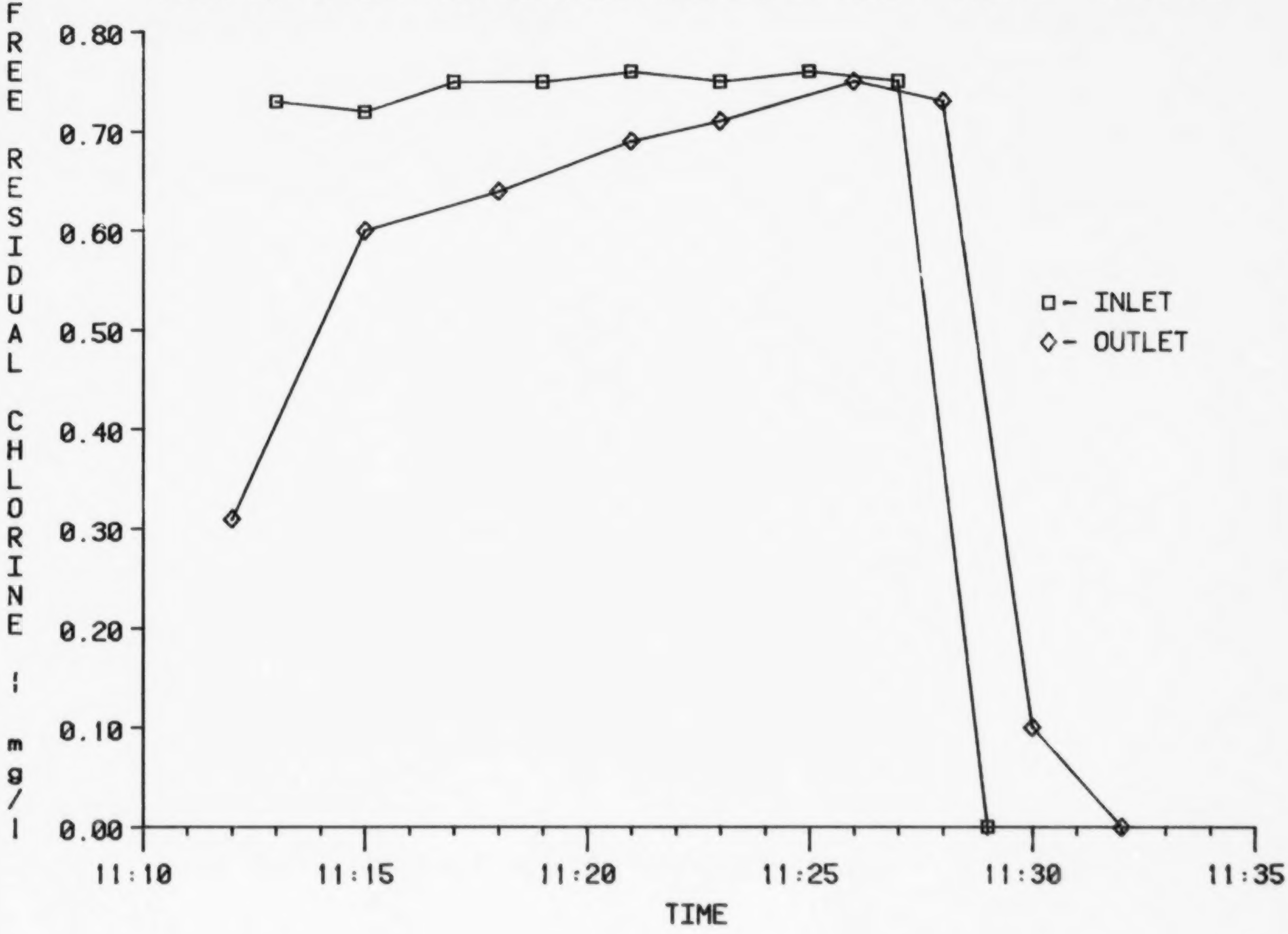


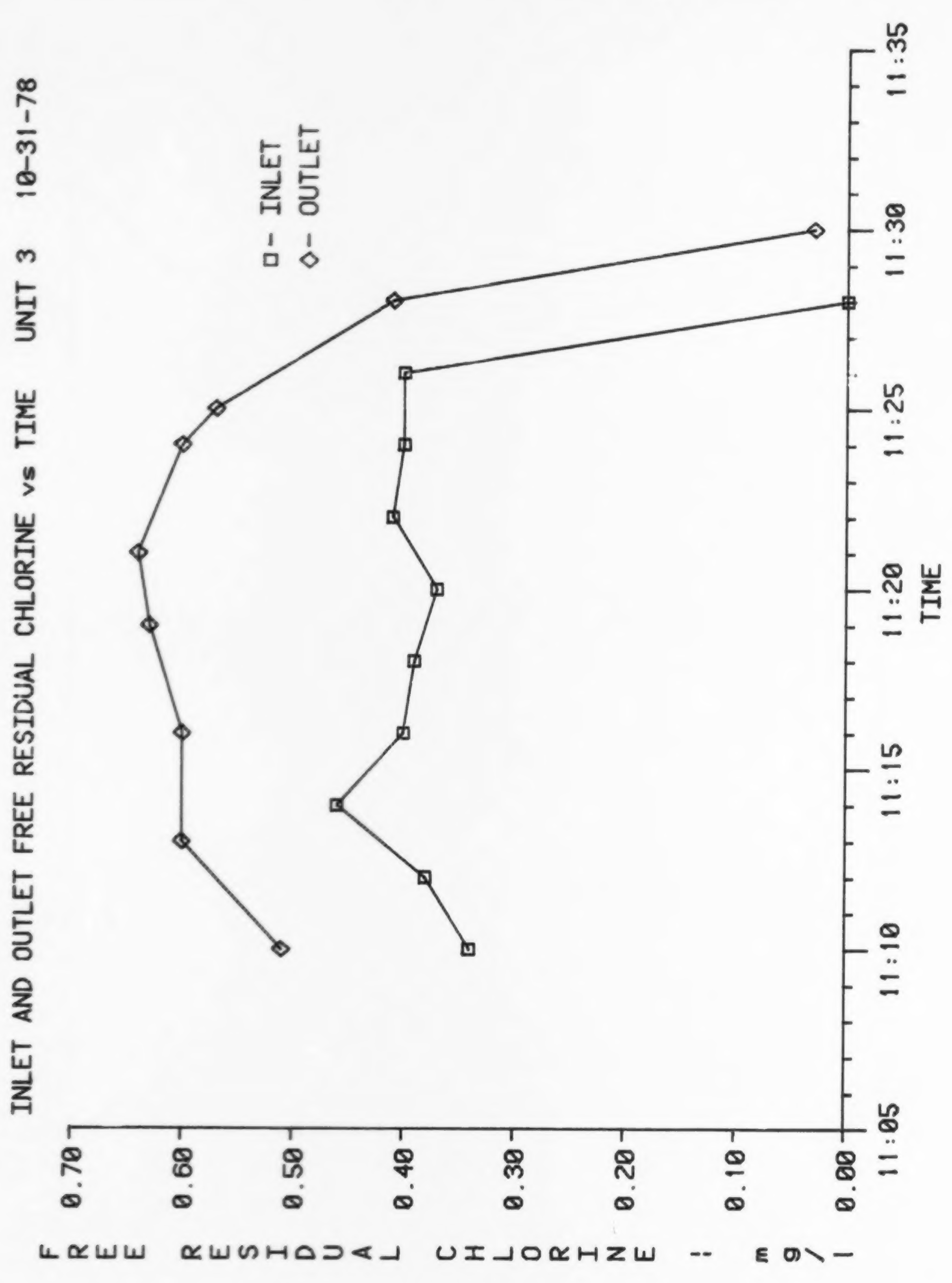
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 9-6-78


INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 9-19-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE - mg/l
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
11:00
11:05
11:10
11:15
11:20
11:25
11:30
11:35
TIME

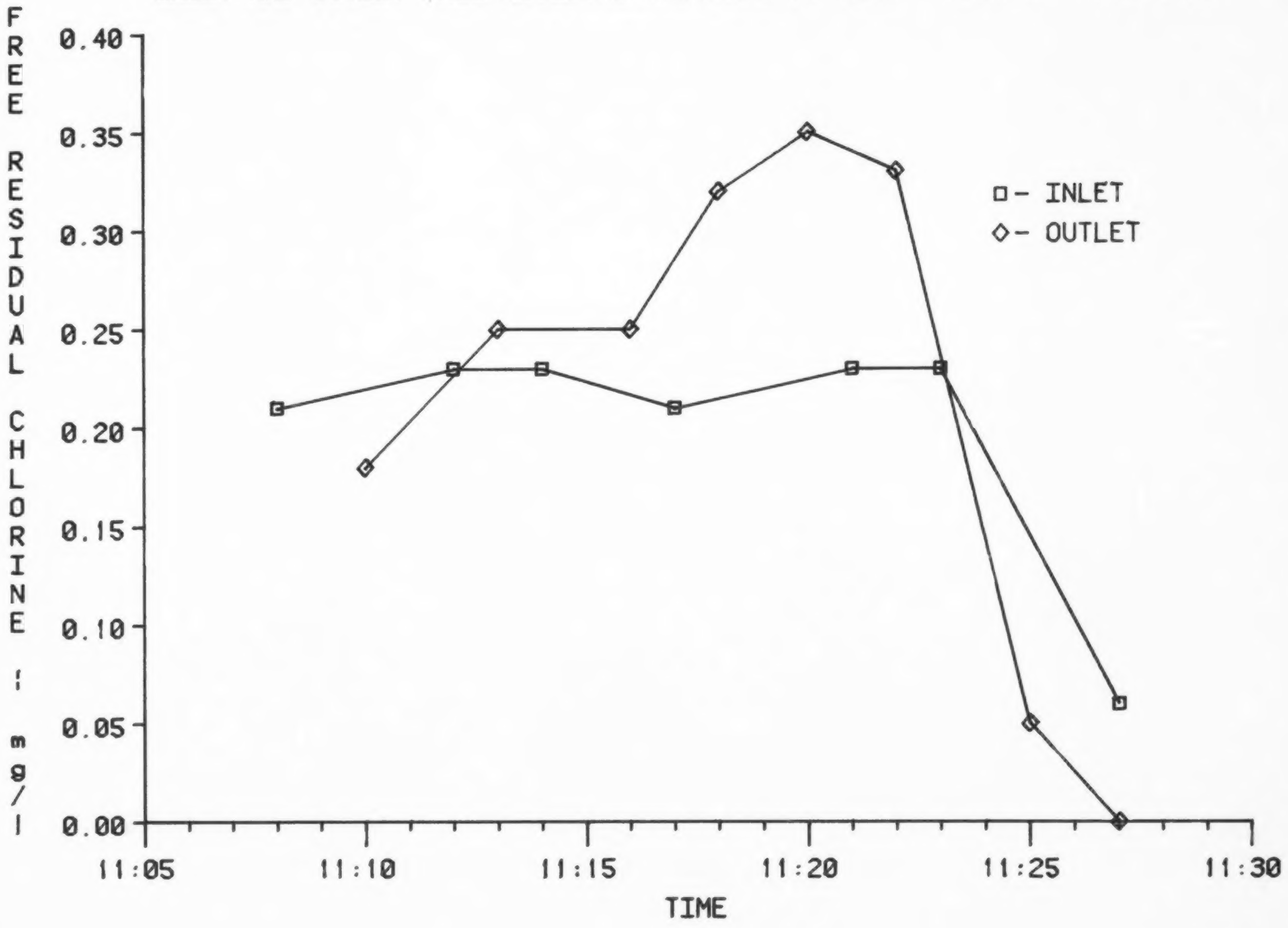

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 10-3-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE -- mg/l
0.25
0.20
0.15
0.10
0.05
0.00
TIME
11:05
11:10
11:15
11:20
11:25
11:30
11:35

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 10-17-78

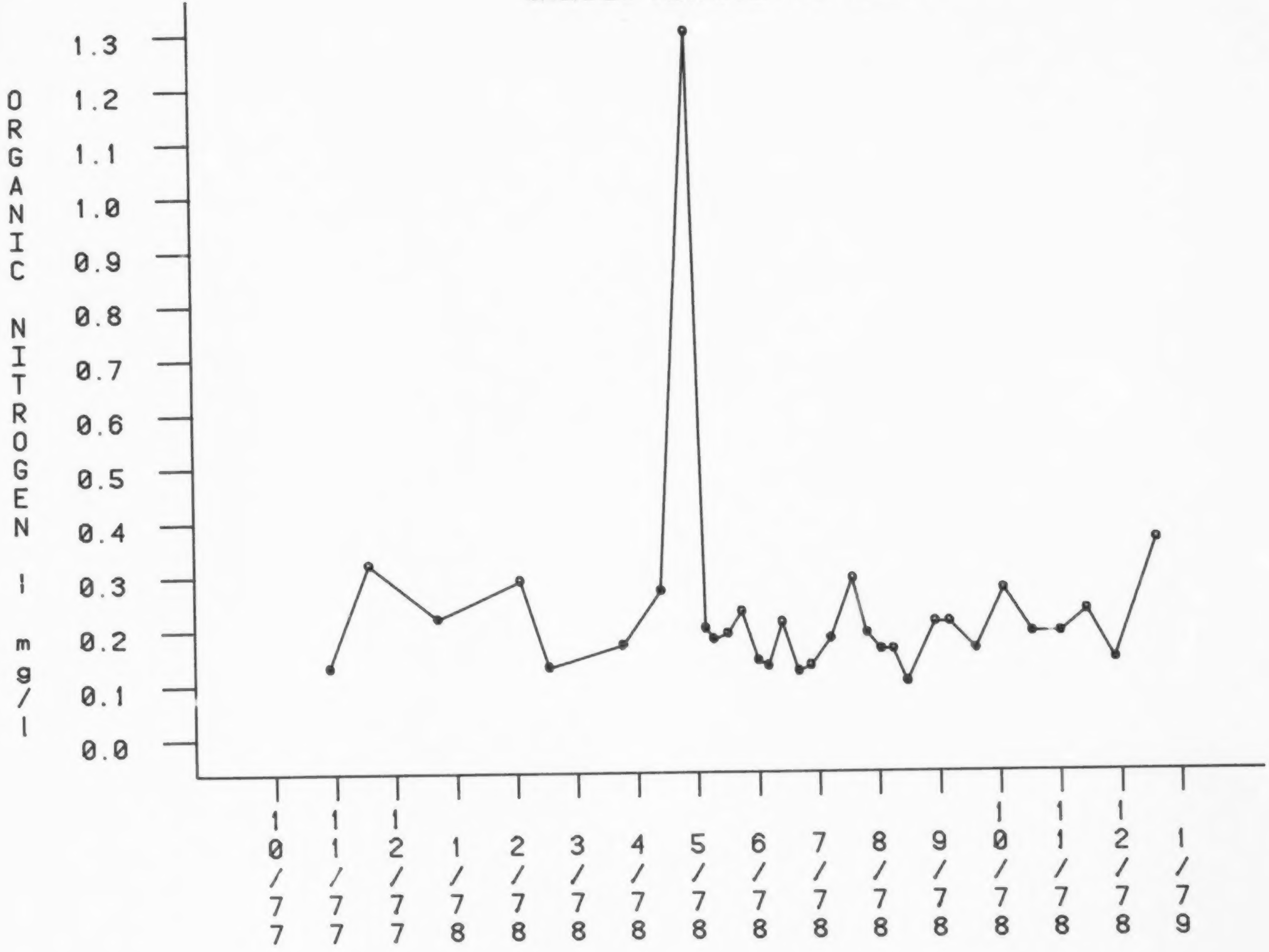


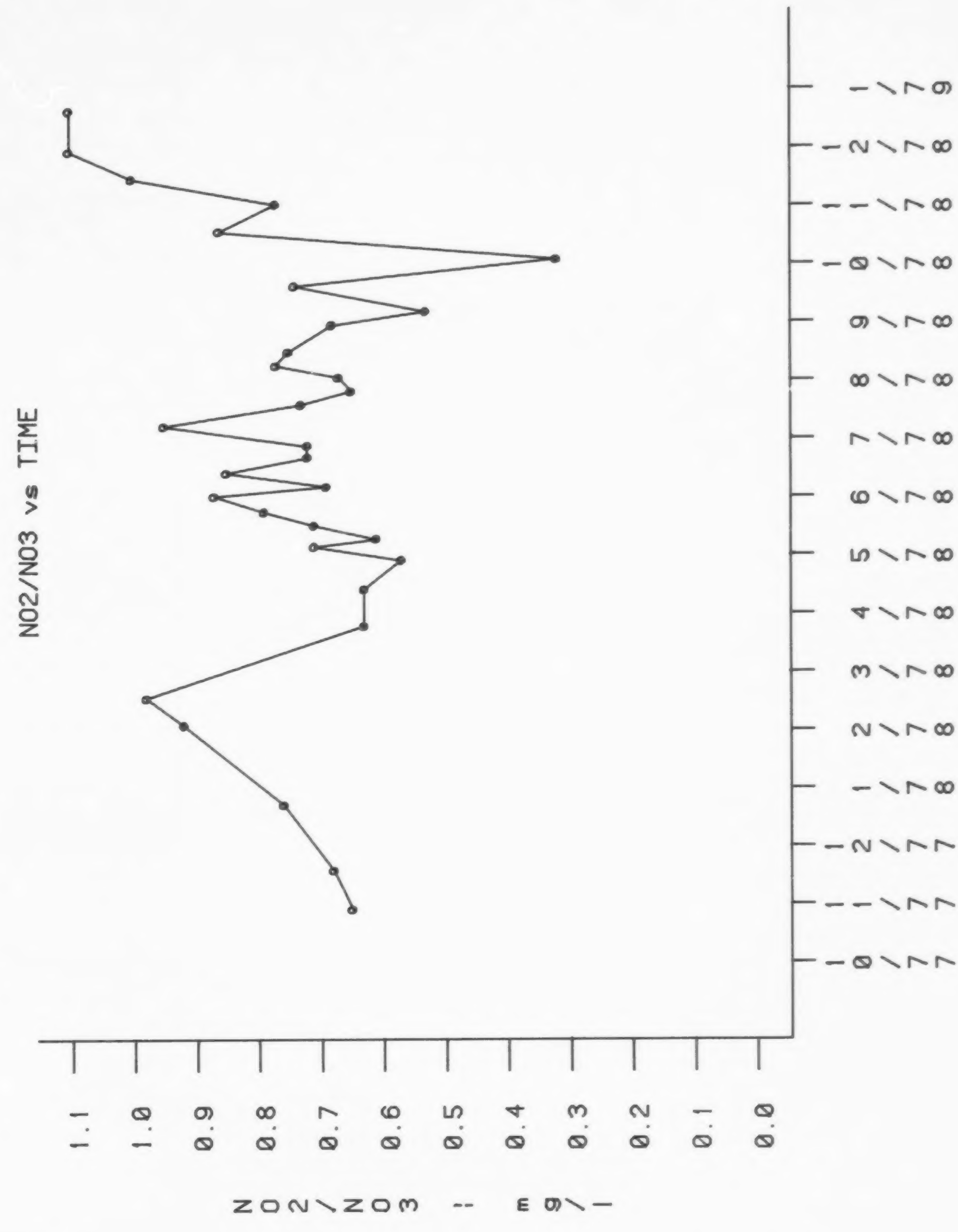

INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 10-31-78
□- INLET
◇- OUTLET
FREE RESIDUAL CHLORINE : mg/l
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
TIME
11:05
11:10
11:15
11:20
11:25
11:30
11:35

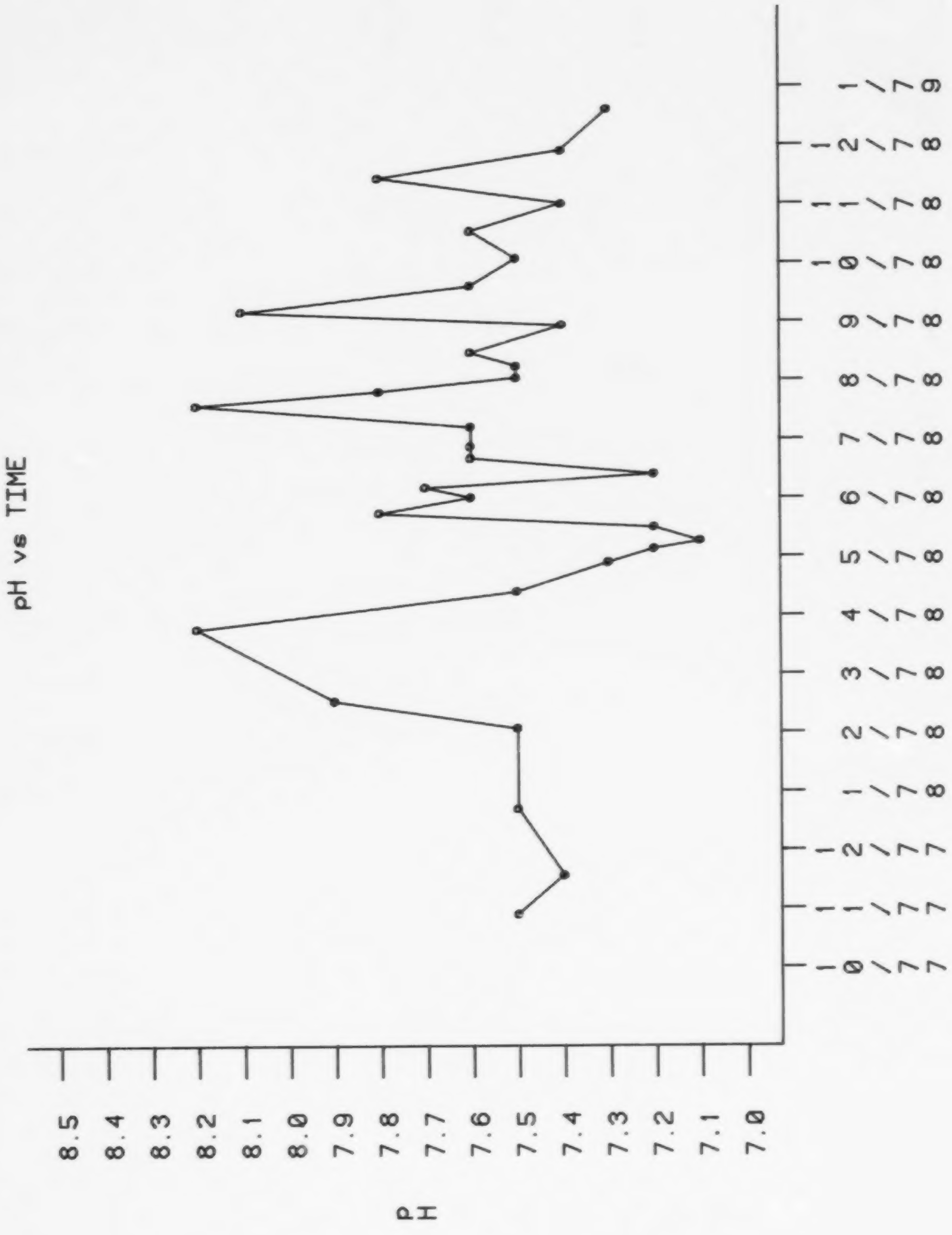
INLET AND OUTLET FREE RESIDUAL CHLORINE vs TIME UNIT 3 11-14-78

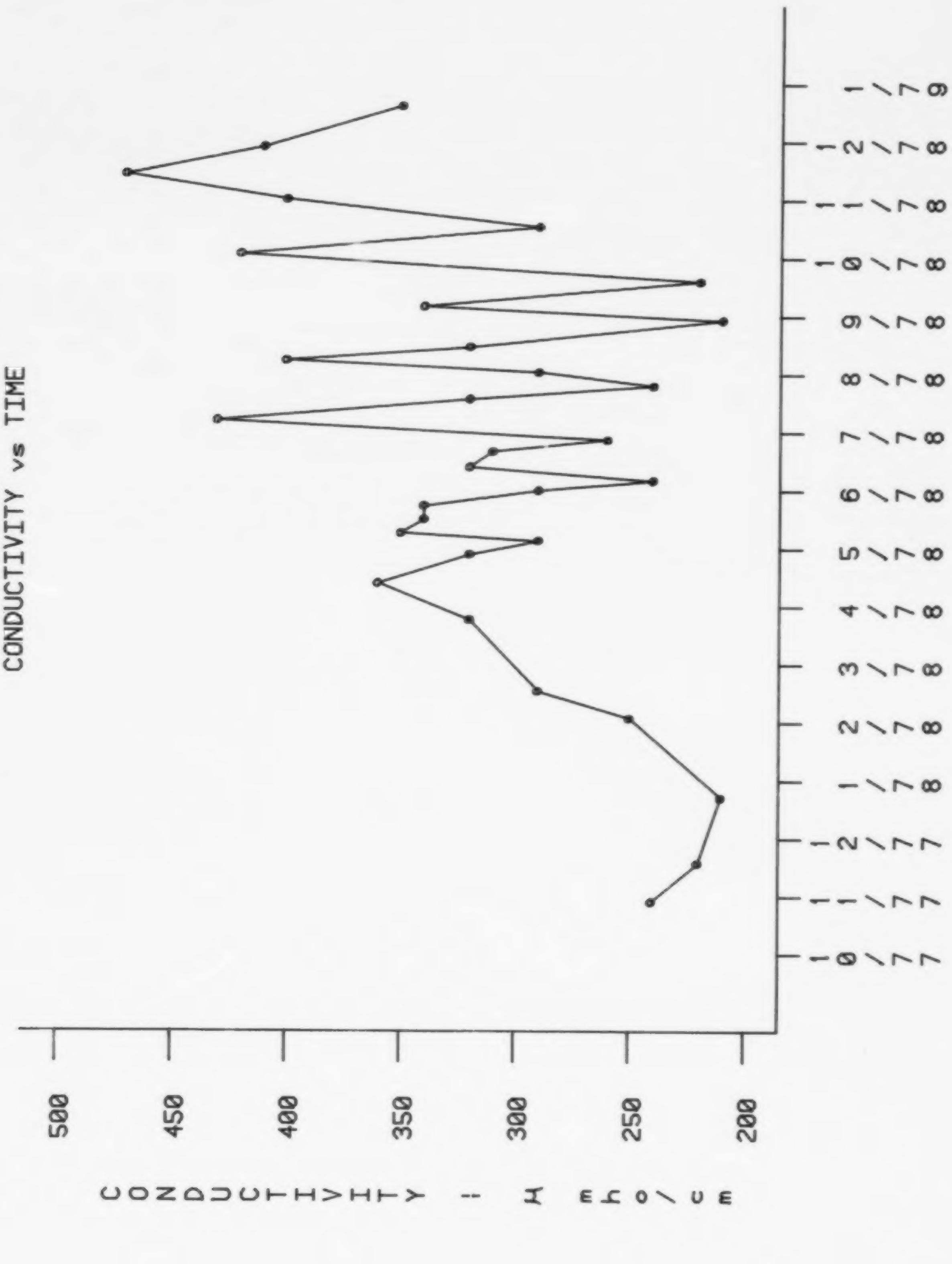


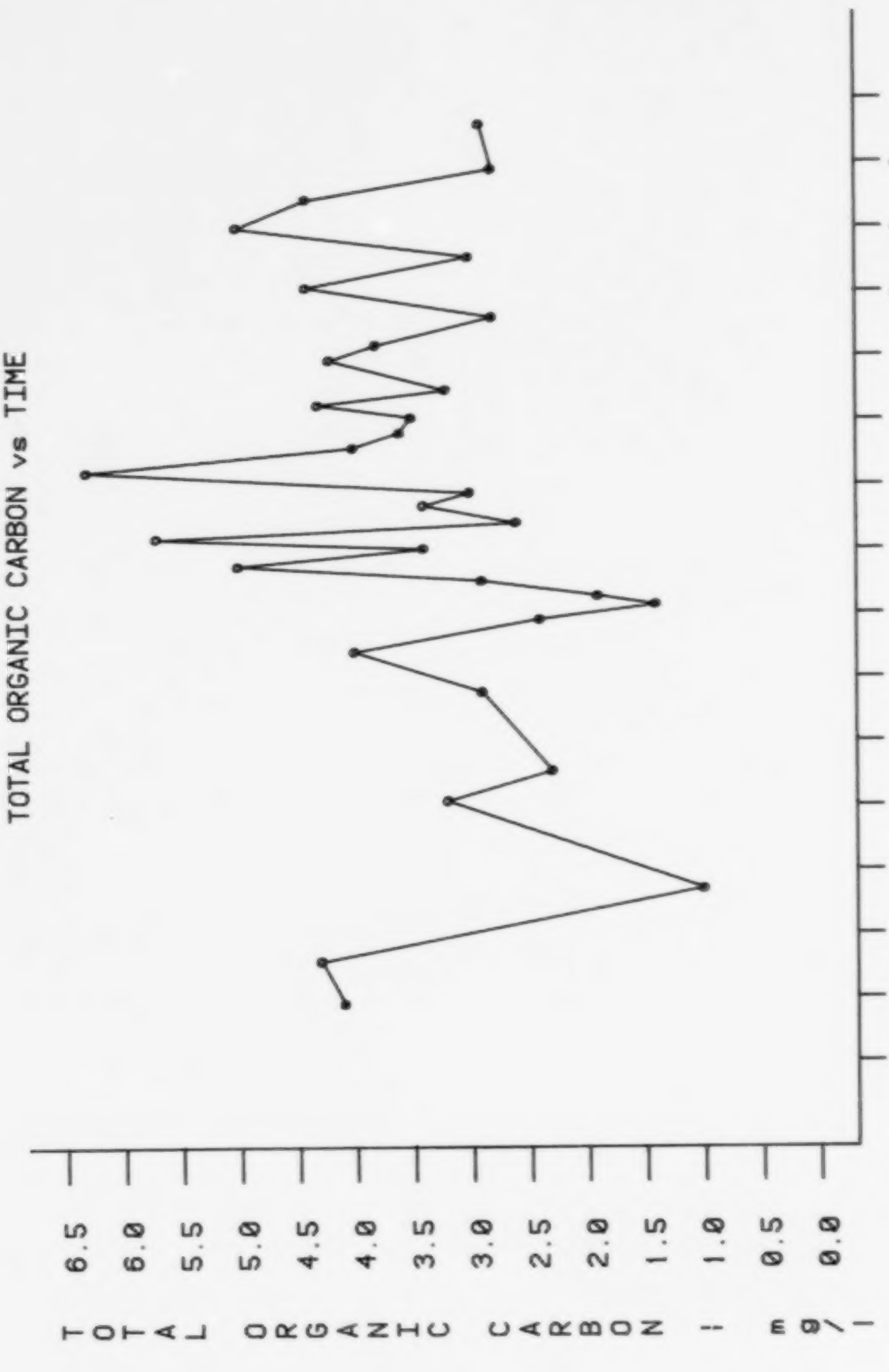
ORGANIC NITROGEN vs TIME

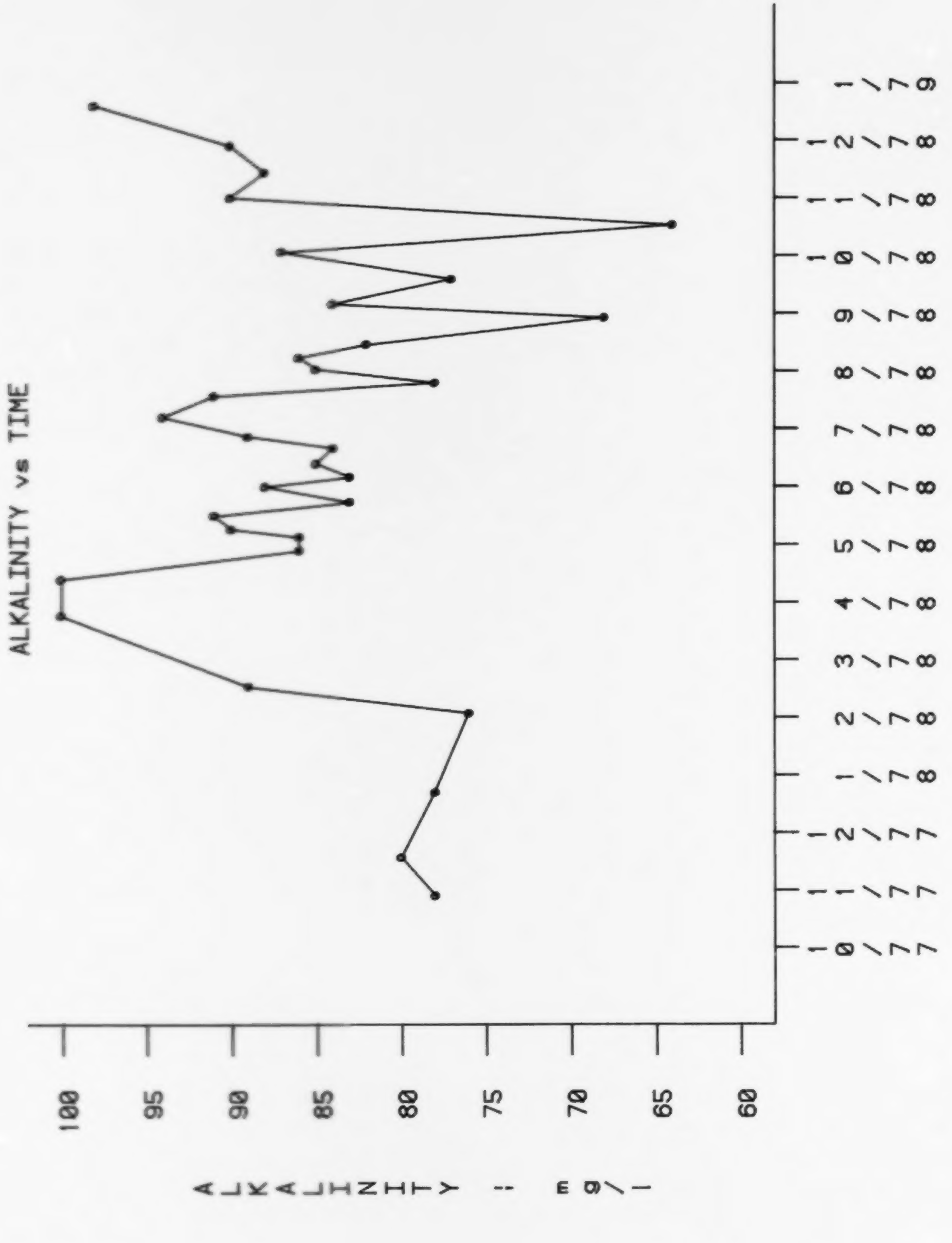


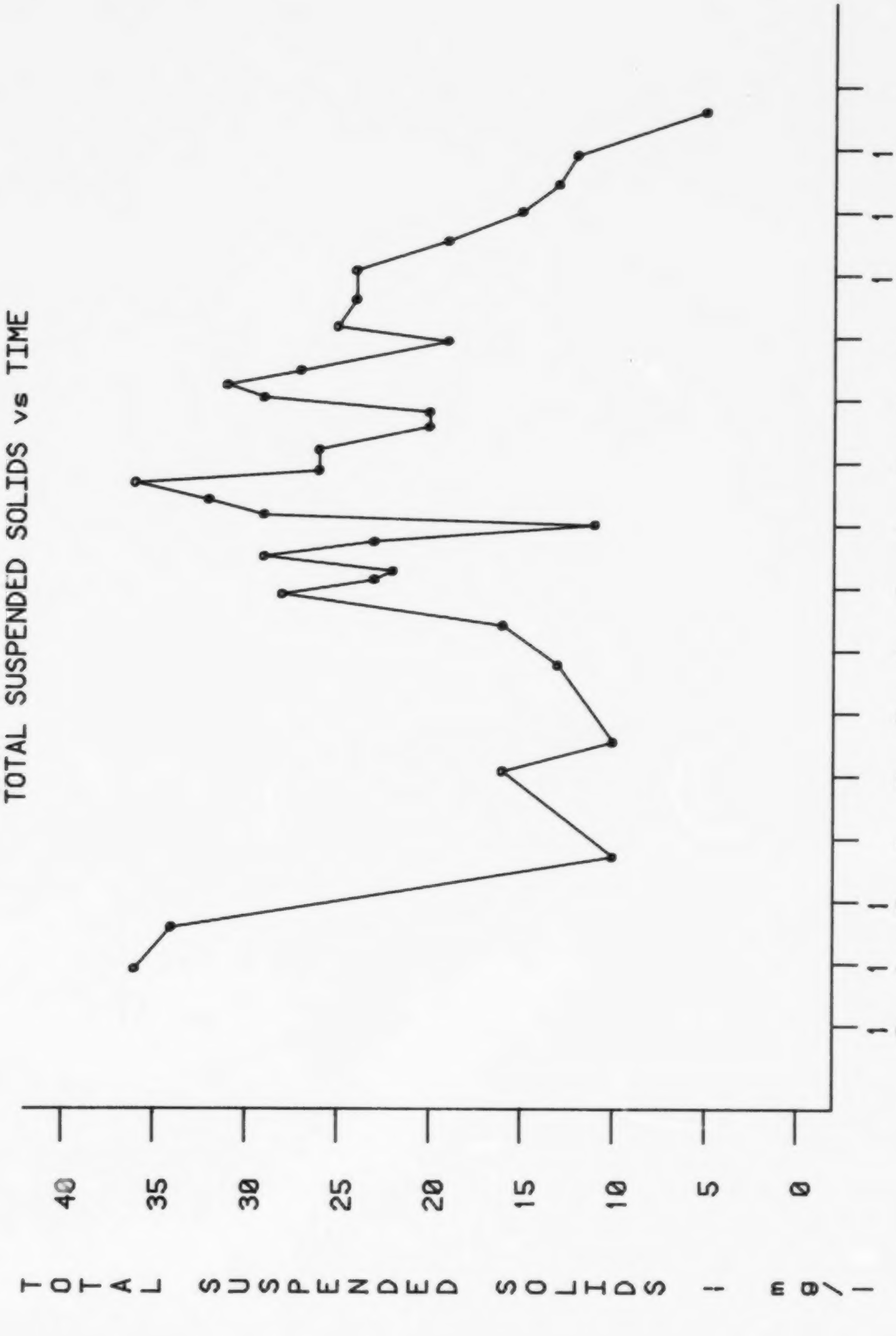

NO2/NO3 vs TIME
NO2/NO3 -- mg/l
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79

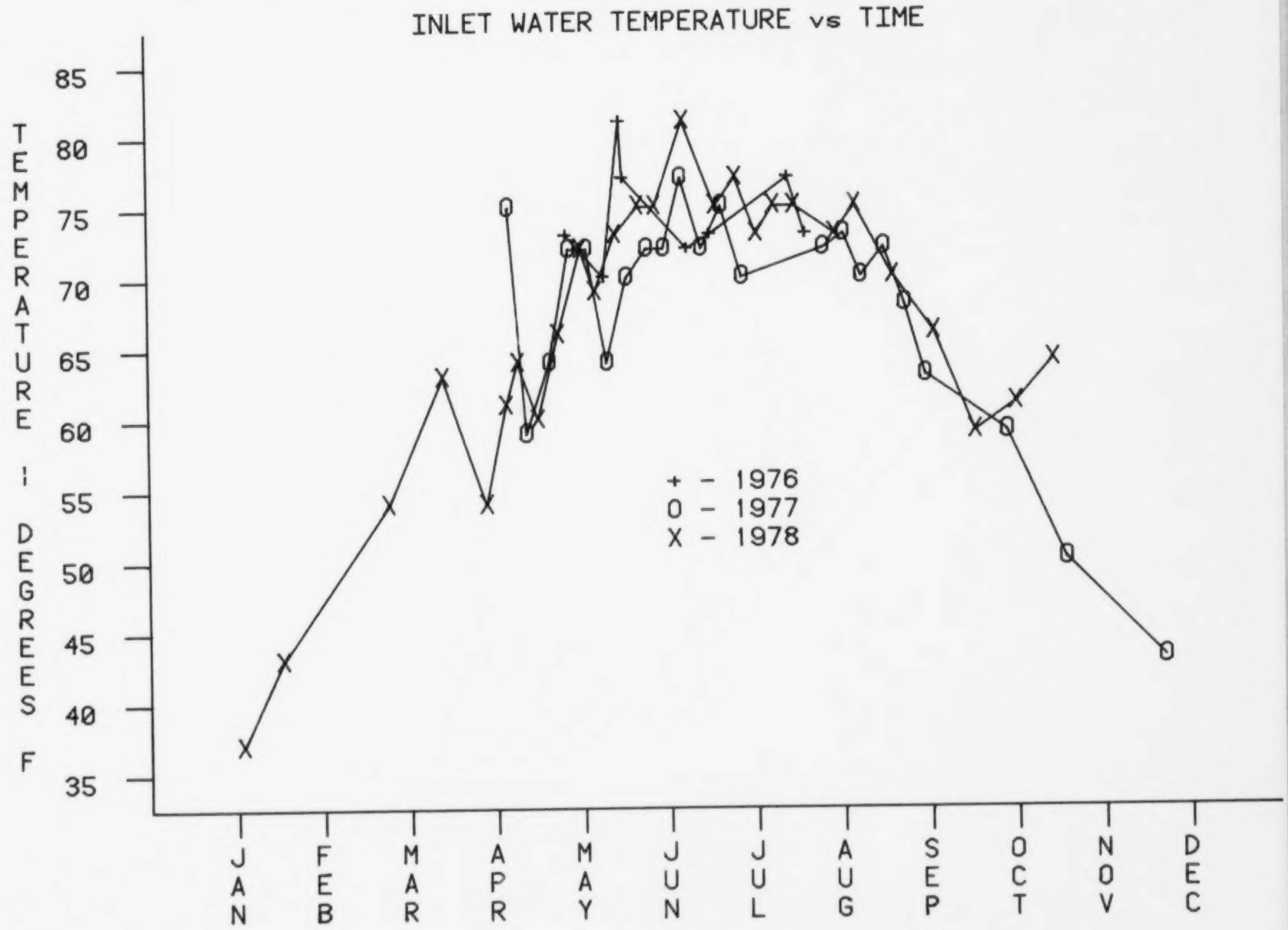

pH vs TIME
pH
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79


CONDUCTIVITY vs TIME
CONDUCTIVITY -- uMHOS/CM
500
450
400
350
300
250
200
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79


TOTAL ORGANIC CARBON vs TIME
TOTAL ORGANIC CARBON - mg/l
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79


ALKALINITY vs TIME
ALKALINITY -- mg/l
100
95
90
85
80
75
70
65
60
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79


TOTAL SUSPENDED SOLIDS vs TIME
TOTAL SUSPENDED SOLIDS - mg/l
0
5
10
15
20
25
30
35
40
10/77
11/77
12/77
1/78
2/78
3/78
4/78
5/78
6/78
7/78
8/78
9/78
10/78
11/78
12/78
1/79


INLET WATER TEMPERATURE vs TIME
TEMPERATURE - DEGREES F
85
80
75
70
65
60
55
50
45
40
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
+ - 1976
0 - 1977
X - 1978

APPENDIX C

WATER TEMPERATURE VERSUS OTHER VARIABLES

APPENDIX C

INLET WATER TEMPERATURE VERSUS OTHER VARIABLES

Inlet water temperature was examined and adjusted for as a covariate in the condenser performance analysis. It was also examined briefly regarding its effects on chlorine consumption. This section examines, briefly, inlet water temperature and possible relationships with turbine back pressure and water quality parameters.

I. Turbine Back Pressure

Based on an analysis of 34 data points during Phase II, turbine back pressure exhibits a general linear trend over the range of inlet water temperatures of 54°F to 76°F. The simple correlation coefficient is 0.8. The average rate of change of turbine back pressure per unit change in inlet water temperature is 0.033. Variation in turbine back pressure appears to be fairly constant over the range of inlet water temperatures. The data may be found in Table C-1.

Table C-1

WATER TEMPERATURE VERSUS OTHER VARIABLES

Date	Inlet Water Temperature	Turbine Back Pressure	Unit
05-06-77	71.0	1.53	1
05-06-77	.	1.67	2
05-06-77	69.0	1.66	3
05-06-77	69.0	1.53	4
05-12-77	62.0	.	1
05-12-77	.	.	2
05-12-77	60.0	.	3
05-12-77	64.0	.	4
05-20-77	68.0	1.97	1
05-20-77	.	.	2
05-20-77	66.0	1.63	3
05-20-77	69.0	1.73	4
05-27-77	74.0	.	1
05-27-77	71.0	.	2
05-27-77	71.0	.	3
05-27-77	72.0	.	4
06-03-77	72.0	2.03	1
06-03-77	71.0	2.17	2
06-03-77	71.0	1.91	3

Continued

Table C-1 (Continued)

Date	Inlet Water Temperature	Turbine Back Pressure	Unit
06-03-77	71.0	1.92	4
06-10-77	66.0	.	1
06-10-77	62.0	.	2
06-10-77	64.0	.	3
06-10-77	64.0	.	4
06-17-77	74.0	1.91	1
06-17-77	73.0	1.95	2
06-17-77	72.0	1.74	3
06-17-77	72.0	1.75	4
06-24-77	71.0	.	1
06-24-77	71.0	.	2
06-24-77	69.0	.	3
06-24-77	71.0	.	4
06-30-77	72.0	1.77	1
06-30-77	71.0	1.83	2
06-30-77	70.0	1.83	3
06-30-77	70.0	1.92	4
07-06-77	82.0	1.79	1
07-06-77	79.5	1.83	2
07-06-77	80.0	1.84	3
07-06-77	79.0	1.92	4
07-13-77	76.0	.	1
07-13-77	74.0	.	2
07-13-77	74.0	2.03	3
07-13-77	74.0	2.12	4
07-27-77	75.0	2.26	1
07-27-77	71.0	2.21	2
07-27-77	72.0	.	3
07-27-77	72.0	2.38	4
07-27-77	75.0	2.26	1
07-27-77	71.0	2.21	2
07-27-77	72.0	.	3
07-27-77	72.0	2.38	4
09-02-77	76.0	.	1
09-02-77	75.0	.	2
09-02-77	75.0	.	3
09-02-77	74.0	.	4
09-09-77	71.0	1.84	1
09-09-77	71.0	1.77	2
09-09-77	72.0	1.82	3
09-09-77	71.0	1.95	4
09-16-77	73.0	.	1
09-16-77	72.0	.	2
09-16-77	72.0	.	3
09-16-77	72.0	.	4

Continued

Table C-1 (Continued)

Date	Inlet Water Temperature	Turbine Back Pressure	Unit
09-23-77	71.0	1.85	1
09-23-77	68.0	1.76	2
09-23-77	69.0	2.01	3
09-23-77	68.0	1.89	4
09-30-77	67.0	.	1
09-30-77	66.0	.	2
09-30-77	65.0	.	3
09-30-77	65.0	.	4
10-28-77	61.0	1.73	1
10-28-77	59.0	1.52	2
10-28-77	.	1.48	3
10-28-77	.	1.56	4
11-19-77	54.0	1.52	1
11-19-77	55.0	1.22	2
11-19-77	55.0	1.41	3
11-19-77	55.0	1.35	4

II. Water Quality Parameters

As a result of the analysis of Phase III, the following table identifies the water quality parameters which correlate fairly well with inlet water temperature. The simple correlation coefficient is given.

Table C-2

FACTORS CORRELATED WITH INLET WATER TEMPERATURE

Factor	Correlation Coefficient
ACF	-0.59
Total Suspended Solids	0.50
Ammonia	-0.41
Organic Nitrogen	-0.42
Total Nitrates-Nitrites	-0.34
FRC Consumed in Condenser	-0.34
TRC consumed in Condenser	-0.52
Kjeldahl Nitrogen	-0.47

APPENDIX D

CHLORINE DEMAND VERSUS FEED RATE AND WATER QUALITY PARAMETERS

APPENDIX D

CHLORINE DEMAND VERSUS FEED RATE AND WATER QUALITY PARAMETERS

Analysis of the chlorine demand of river water from Unit 3 with contact times of 1, 5, and 10 minutes was examined for possible relationships with inlet water temperature, water quality parameters, and chlorine dosage.

The following table lists the variables which correltated well with the 1-, 5-, and 10-minute chlorine demands for Phase III.

Table D-1

CORRELATION COEFFICIENTS FOR 1-, 5-, AND 10-MINUTE DEMANDS FOR UNIT 3 WITH OTHER FACTORS

Variable	1 min.	Variable	5 min.	Variable	10 min.
FRC at Condenser Inlet	-0.81	CL_2	0.89	CL_2	0.88
Conductivity	0.74	Inlet Water Temperature	0.74	Inlet Water Temperature	0.73
Ammonia	0.79	Total Suspended Solids	0.82	Total Suspended Solids	0.73
Kjeldahl Nitrogen	0.72	Total Organic Carbon	0.67	Total Organic Carbon	0.76
		Ammonia	0.79	Ammonia	0.73

Due to the intercorrelation between the various water quality parameters, an analysis was carried out to try to explain the variation of the 1-, 5-, and 10-minute demands as a function of chlorine dosage, inlet water temperature, and the water quality parameters. Regression analysis was used to develop the models.

I. Modeling the One-Minute Chlorine Demand

After using regression analysis to analyze the data, it was noted that the relationships of the one-minute demand to chlorine dosage, inlet water temperature, and the other water quality parameters were completely random. No discernable and consistant relationships existed. There was, however, a slightly negative relationship between total organic carbon and the one-minute demand; but the analysis is not conclusive.

II. Modeling the Five-Minute Chlorine Demand

The best model found to explain the variation in the five-minute chlorine demand is

$$Y_2 = -1.4254 + 0.4797\ Cl_2 + 0.1451\ pH$$

where Y_2 is the five-minute demand, Cl_2 is the chlorine dosage at the intake, and pH is the pH of the intake water. This model explains 76 percent of the variation in the five-minute demand. The error mean square is .0059, and the model's F-statistic is 64.30, which is highly significant.

III. Modeling the 10-Minute Chlorine Demand

The best model found to explain the variations in the 10-minute demand is

$$Y_3 = -1.9711 + .6534\ Cl_2 + .2285\ pH - .0801\ TOC$$

where Y_3 is the 10-minute chlorine demand, Cl_2 is the chlorine dosage at the intake, and TOC is the total organic carbon. This model explains 74 percent of the variation of the 10-minute demand. The error mean square is .0122, and the model's F-statistic is 36.40, which is highly significant.

IV. Discussion of the Models

The models exhibit some expected and unexpected behavior. Both the 5- and 10-minute demands show a relationship with the chlorine dosage and the pH. This is expected. The inverse relationship of TOC and the demands is somewhat unexpected. This relationship may give us insight with respect to the negative chlorine consumption discussed in Appendix A.

Another unexpected result was that ammonia, Kjeldahl nitrogen, and organic nitrogen concentrations did not significantly impact the chlorine demands as much as Cl_2, pH, and TOC did. Therefore, these models should be used with utmost care.

APPENDIX E

COMPLEXITY OF ORGANIC MATERIALS IN THE WATER

APPENDIX E

COMPLEXITY OF ORGANIC MATERIALS IN THE WATER

An analysis was also made of the chlorine demand test data for the river water at John Sevier Steam Plant. The formula used for this analysis was:

$$D = kt^n$$

where:

D = demand of the water (feed - residual)
k = chlorine demand after 30 minutes, ppm
t = contact time in % of 30 minutes
n = slope of curve (tan θ)

$$D = kt^n$$

$$\frac{D}{k} = t^n$$

$$\log \frac{D}{k} = n \log t$$

$$\frac{\log \frac{D}{k}}{\log t} = n$$

The above formula was developed and extensively researched and tested by Douglas Feben and Michael J. Taras using Detroit's water supply as the major source of samples.[16,17,18]

The usefulness of this basic equation derived from measuring chlorine demands is the variation in the exponent n (i.e., the slope of the demand curve). The value of the exponent n reveals the speed of the reaction and is theoretically related to the nature of the organic material involved in the reactions with chlorine. Inorganic ions such as NH^3, Fe^{++}, and S^{-2} react instantaneously, causing rapid initial chlorine demand. This causes the exponent n to approach zero. Other results obtained from well waters in the greater Detroit metropolitan area and Long Beach, California, show remarkably similar exponential values varying between 0.01 for the Long Beach wells to 0.03-0.07 for the Detroit area wells. A chemical analysis of the well samples indicated the presence of the three most rapid chlorine-consuming substances--ammonia nitrogen, sulfide, and ferrous ions. Also, some simple unsubstituted amino acids were present; all of these substances resulted in the low exponential value.

As the value of the exponent increases, the more complicated the organic material becomes. Of the organic materials, Feben and Taras found that the simple amino acids were generally found to react most readily with chlorine, whereas complex molecules like peptides and proteins were found to react more slowly.[16] The surface waters tested contained sizable amounts of complex organic material and traces of ferric ions as opposed to ferrous ions. This analysis substantiated the high exponential values calculated with the formula $D = kt^n$.[16,17,18]

In one series of tests conducted by Taras, several simple and complex organic and inorganic substances were tested for their individual chlorine demands; the simple and the inorganic materials resulted in low exponential values (0.02-0.19), and the complex organic materials resulted in high exponential values (0.19-0.30).[18]

The exponential reaction constant as a function of time is dependent upon the individual structure of the amino acid. An increase in the structural complexity results in higher values of the reaction constant n, and will, therefore, exhibit prolonged chlorine demand. A significant rise in the value of n would indicate a rise in the organic nitrogen present and, further, a deterioration in the raw water quality.[3]

The resulting application of this equation to data from the water samples taken during testing at John Sevier is found in Table E-1. A representative graph of the results may be found in Figure E-1.

Based on the data, identification of the complexity of the materials in the water using White's procedure was statistically inconclusive. The variation of the slopes did not correlate well with the available field data.

Table E-1

CHLORINE DEMAND UNIT 3

Phase I

'76	mg/l	Cl Demand		N*		
Date	Feed Rate	10 min	30 min	Slope	Total N	% Organic N
6/9	3.75	2.1	2.7	0.23	1.17	11
6/16	3.09	2.7	2.65	-0.017	1.33	23
7/7	2.68	2.3	2.1	-0.082	1.20	19
7/8	2.68	1.4	2.1	0.37	1.32	29
7/16	3.13	1.7	2.3	0.27	0.89	23
		5 min	10 min			
8/13	3.63	0.7	1.1	0.65	0.98	24
8/19	2.82	0.9	1.9	1.08	1.01	22

Phase II

'77	mg/l	Cl Demand			N*		
Date	Feed Rate	1 min	5 min	10 min	Slope	Total N	% Organic N
5/12	3.28	0.80	0.56	0.68	0.28	0.92	16.3
5/20	2.85	0.17	0.55	0.75	0.45	1.0	18
5/27	2.82	0.43	0.92	1.31	0.51	1.15	23.5
6/3	2.79	0.41	0.90	1.29	0.52	0.98	24.5
6/10	2.80	0.17	0.55	0.75	0.45	0.77	19.5
6/17	2.81	0.31	0.59	1.10	0.90	0.87	12.6
6/24	2.73	0.34	0.89	0.99	0.15	1.09	30.3
6/30	2.82	0.47	0.77	1.12	0.54	0.83	21.7
7/13	2.83	0.47	0.75	1.12	0.58	0.87	16.1
7/20	2.85	0.29	0.66	0.92	0.48	0.70	20
8/18	2.83	0.70	1.03	1.32	0.36	0.65	23.1
9/2	1.65	0.30	0.40	0.55	0.46	0.90	17.8
9/9	1.70	0.20	0.39	0.62	0.67	0.98	15.3
9/16	1.72	0.29	0.50	0.61	0.29	1.06	17.9
9/23	1.77	0.28	0.39	0.67	0.78	0.93	21.5

Table E-1
(Continued)

Phase III

Date	Feed Rate	Cl Demand 1 min	Cl Demand 5 min	Cl Demand 10 min	N* Slope	Total N	% Organic N
10/28/77	1.11	.22	.29	.30	.05	.85	15
11/18/77	1.25	.30	.39	.51	.39	1.06	30
12/22/77	1.11	.11	.23	.28	.28	1.02	22
2/3/78	1.22	.16	.22	.30	.45	1.42	20
2/17/78	1.19	.13	.20	.28	.49	1.18	11
3/24/78	1.19	.23	.28	.48	.78	.89	19
4/13/78	1.15	.02	.10	.01	-3.3	1.39	19
4/28/78	1.92	.12	.39	.51	.39	.80	16
5/5/78	1.88	.27	.45	.61	.44	1.08	19
5/9/78	2.21	.21	.59	.77	.39	.94	19
5/16/78	2.27	.34	.71	.90	.26	1.09	17
5/23/78	2.11	.43	.75	.89	.25	1.17	20
5/31/78	2.19	.50	.73	.95	.38	1.17	12
6/6/78	2.20	.02	.60	.69	.20	.91	14
6/13/78	1.85	.28	.47	.74	.66	1.16	18
6/21/78	1.86	.27	.52	.61	.28	.94	13
6/27/78	1.83	.19	.49	.58	.24	.93	14
7/07/78	1.81	.28	.48	.59	.25	1.28	14
7/18/78	1.50	.26	.49	.57	.21	1.17	25
7/25/78	1.54	0	.37	.41	.15	.91	21
8/2/78	1.58	.38	.45	.56	.32	.95	17
8/8/78	1.52	.10	.39	.46	.24	1.09	15
8/15/78	1.62	.40	.65	.67	.04	.95	11
8/29/78	1.59	.20	.48	.55	.20	.96	22
9/6/78	1.56	.31	.58	.65	.16	.81	26
9/19/78	1.56	.19	.31	.48	.63	.98	16
10/3/78	1.92	.37	.70	.73	.06	.70	39
10/17/78	1.92	.30	.60	1.00	.74	1.18	16
10/31/78	1.92					1.17	16
11/14/78	1.98	.59	.79	.89	.17	1.34	17
11/28/78	1.98	.59	.99	1.09	.14	1.40	10
12/19/78	1.98	.11	.40	.39	-.04	1.52	24

$$*N = \frac{\log \frac{D}{K}}{\log t}$$

D = 5 min demand
K = 10 min demand
t = % of 10 min (.5)
(For dates 6/9/76-8/19/76, D = 10-minute demand; K = 30-minute demand; t = % of 30 min [.33].)

$$\text{Chlorine Feed Rate} = \frac{\text{Feed Rate (lb/day)}}{\text{Flow Rate (gal/min)}} \times 83.22 = \text{mg/l } Cl_2$$

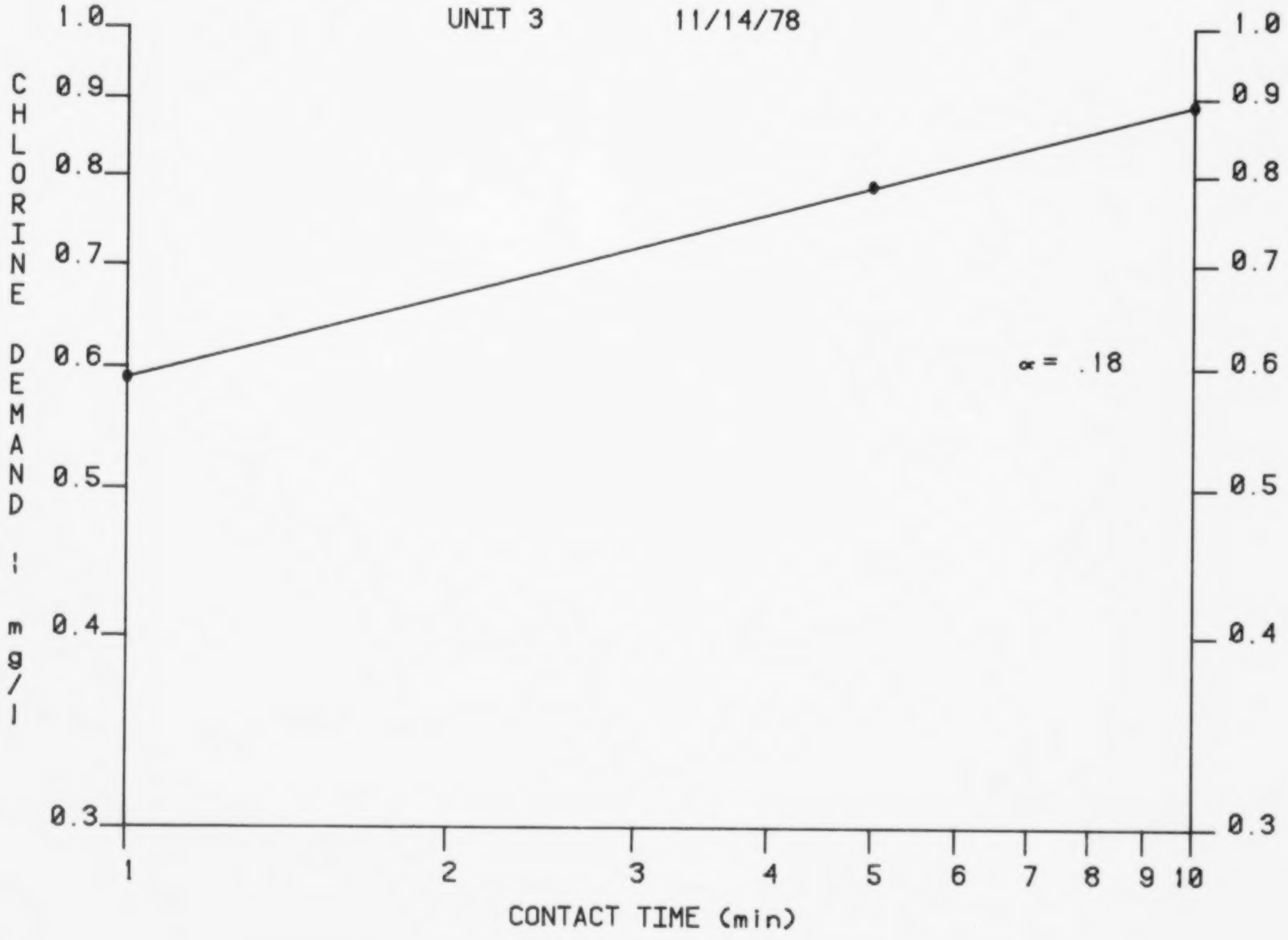


FIGURE E-1. SLOPE OF CHLORINE DEMAND CURVE (log)

APPENDIX F

DPD VERSUS AMPEROMETRIC TITRATOR DATA

APPENDIX F

DPD VERSUS AMPEROMETRIC TITRATOR

I. DISCUSSION

On nine test dates in 1977 outlet free and total residual chlorine were measured by both the amperometric and DPD methods on Unit 1. The use of both methods allowed a statistical comparison on the equality of the two methods. The raw data gathered on the nine test dates may be found in Tables F-1 through F-4. Table F-5 summarizes a paired samples analysis carried out on the data. At a significance level of 0.10, there is a significant difference between the two methods for both free and total residual chlorine. Based on the differences calculated, DPD is consistently higher than the amperometric method.

A further examination of the calculated differences shows that negative differences occur at low levels of concentration approximately 0.5 mg/l and less. This indicates the measurements by the two methods may depend on the level of the concentration and possibly bias the comparison between the two methods. Section II summarizes a paired samples analysis of free and total residual chlorine where the effect of the level of concentration has been removed.

II. REMOVING THE EFFECT OF LEVEL OF CONCENTRATION FROM DPD AND AMPEROMETRIC DATA

The true concentration was estimated as the mean of the observed DPD and amperometric readings for both free and residual chlorine. The estimated true concentration was then fitted by regression analysis as a linear function of the observed data for each method. This allowed adjusting of the DPD and amperometric data to remove the effects of concentration level.

At a significance level of 0.10, there is a significant difference between the two methods for both free and total residual chlorine. The DPD method is significantly higher than the amperometric method in its readings on the chlorine level. Table F-6 summarizes the paired samples analysis on the adjusted data.

Table F-1

FREE RESIDUAL CHLORINE

Date	DPD	Amperometric	Difference
06-10-77	1.12	0.66	0.46
06-17-77	0.86	0.23	0.63
06-30-77	1.11	0.96	0.15
07-13-77	0.92	0.81	0.11
07-20-77	1.12	1.05	0.07
07-27-77	0.11	0.15	-0.04
09-02-77	0.23	0.26	-0.03
09-08-77	0.57	0.46	0.11
09-16-77	0.65	0.60	0.05

Table F-2

TOTAL RESIDUAL CHLORINE

Date	DPD	Amperometric	Difference
06-10-77	1.38	1.21	0.17
06-17-77	1.36	1.23	0.13
06-30-77	1.35	1.35	0.00
07-13-77	1.22	1.19	0.03
07-20-77	1.42	1.12	0.30
07-27-77	0.87	0.77	0.10
09-02-77	0.72	0.69	0.03
09-08-77	0.93	0.86	0.07
09-16-77	1.14	1.06	0.08

Table F-3

FREE RESIDUAL CHLORINE - ADJUSTED FOR CONCENTRATION LEVEL

Date	Adjusted DPD	Adjusted Amperometric
07-27-77	0.89	0.79
09-02-77	0.90	0.80
09-08-77	0.92	0.80
09-16-77	0.93	0.80
06-17-77	0.94	0.79
07-13-77	0.95	0.81
06-30-77	0.96	0.82
06-10-77	0.96	0.80
07-20-77	0.96	0.83

Table F-4

TOTAL RESIDUAL CHLORINE - ADJUSTED FOR CONCENTRATION LEVELS

Date	Adjusted DPD	Adjusted Amperometric
09-22-77	0.93	0.81
07-27-77	0.94	0.81
09-08-77	0.95	0.82
09-16-77	0.96	0.82
07-13-77	0.97	0.83
06-30-77	0.98	0.83
06-17-77	0.98	0.83
06-10-77	0.98	0.83
07-20-77	0.98	0.83

Table F-5

SUMMARY OF PAIRED SAMPLES ANALYSIS COMPARING DPD AND AMPEROMETRIC METHODS

Differences = DPD - Amperometric (In Mg/l)

Date	Free Residual Chlorine	Total Residual Chlorine
6-10	0.46	0.17
6-17	0.63	0.13
6-30	0.15	0.00
7-13	0.11	0.03
7-20	0.07	0.30
7-27	-0.04	0.10
9-2	-0.03	0.03
9-8	0.11	0.07
9-16	0.05	0.08
	Mean = 0.1678	Mean = 0.1011
	Variance = 0.0515	Variance = 0.0084
	Calculated t value = 2.22	Calculated t value = 3.31
	df = 8	df = 8
	Alpha = 0.10	Alpha = 0.10

Table F-6

SUMMARY OF PAIRED SAMPLES ANALYSIS COMPARING DPD AND AMPEROMETRIC METHODS AFTER ADJUSTMENT FOR EFFECT OF CONCENTRATION LEVEL

Free Residual Chlorine			Total Residual Chlorine		
DPD	AMP	DIF	DPD	AMP	DIF
0.89	0.79	0.10	0.93	0.81	0.12
0.90	0.80	0.10	0.94	0.81	0.13
0.92	0.80	0.12	0.95	0.82	0.13
0.93	0.80	0.13	0.96	0.82	0.14
0.94	0.79	0.15	0.97	0.83	0.14
0.95	0.81	0.14	0.98	0.83	0.15
0.96	0.82	0.14	0.98	0.83	0.15
0.96	0.80	0.16	0.98	0.83	0.15
0.96	0.83	0.13	0.98	0.83	0.15
Mean = 0.13			Mean = 0.14		
Variance = 0.000424			Variance = 0.000125		
Calculated t value = 18.94			Calculated t value = 37.50		
df = 8			df = 8		
Alpha = 0.10			Alpha = 0.10		

APPENDIX G

CHLORINATED ORGANICS DATA

TABLE G-1

			Concentrations in ppb (µg/l)		
Sample Point	Sample Number	Date	Chloroform ($CHCl_3$)	Bromodichloromethane ($CHCl_2Br$)	Chlorodibromomethane ($CHClBr_2$)
**Intake Canal	1(F)[a]	7/06/78	<1.0	<0.5	<0.5
	1(L)		<1.0	<0.5	<0.5
Condenser Outlet 30 mins after chlorination started	2(F)	7/06/78	1.4	0.9	<0.5
	2(L)		1.7	0.9	<0.5
Condenser Outlet 5 mins after chloronation was ended	3A(F)	7/06/78	<1.0	<0.5	<0.5
	3A(L)		<1.0	<0.5	<0.5
*Intake Canal	3B(F)	7/06/78	<1.0	<0.5	<0.5
	3B(L)		<1.0	<0.5	<0.5
**Intake Canal	1(F)	7/25/78	<1.0	<0.2[b]	<0.2[b]
	1(L)		<1.0	<0.2	<0.2
Condenser Outlet[c] 8 mins into chlorination cycle	2A(F)	7/25/78	2.1	0.9	0.2
	2A(L)		3.8	1.3	0.3
Condenser Outlet[c] 16 mins into chlorination cycle	2B(F)	7/25/78	2.6	1.2	0.3
	2A(L)		4.1	1.4	0.3
Condenser Outlet 5 mins after chlorination cycle	3A(F)	7/25/78	<1.0	<0.2	<0.2
	3A(L)		<1.0	<0.2	<0.2
*Intake Canal	3B(F)	7/25/78	<1.0	<0.2	<0.2
	3B(L)		<1.0	<0.2	<0.2

---

a. (F) Field extraction, solvent added to vial before sample collection.
(L) Lab extraction, solvent added to vial in the laboratory.

b. Due to improved analytical techniques, the detection limits for bromodichloromethane and chlorodibromomethane were lowered from <0.5 ppb to <0.2 ppb.

c. Chlorination as of 7/25/78 is now 3 times a day for 20 minutes per cycle.

** Sample taken before chlorination cycle.

* Sample taken after chlorination cycle.

TABLE G-1 (continued)

Sample Point	Sample Number	Date	Concentrations in ppb (μg/l) Chloroform ($CHCl_3$)	Bromodichloromethane ($CHCl_2Br$)	Chlorodibromomethane ($CHClBr_2$)
**Intake Canal	1[e]	8/29/78	<1.0	<0.2	<0.2
Condenser Inlet[d] 5 mins into chlorination cycle	2	8/29/78	4.8	1.2	0.2
Condenser Outlet 8 mins into chlorination cycle	3	8/29/78	5.4	1.4	0.3
Condenser Outlet 16 mins into chlorination cycle	4	8/29/78	5.2	1.4	0.2
Condenser Outlet 5 mins after chlorination cycle	5	8/29/78	<1.0	<0.2	<0.2
*Intake Canal	6	8/29/78	<1.0	<0.2	<0.2
**Intake Canal	2	9/19/78	<1.0	<0.2	<0.2
Condenser Outlet 8 mins into chlorination cycle	5	9/19/78	3.2	1.0	0.2
Condenser Outlet 16 mins into chlorination cycle	8	9/19/78	5.2	1.6	0.2
Condenser Outlet 5 mins after chlorination cycle	9	9/19/78	1.3	0.5	<0.2
*Intake Canal	11	9/19/78	<1.0	<0.2	<0.2

---

d. The sample for the condenser inlet has been added as of 8/29/78. This sample was added to see if there is a change of concentration across the condenser.

e. As of 8/29/78, all samples will be extracted in the laboratory.

** Sample taken before chlorination cycle.

* Sample taken after chlorination cycle.

TABLE G-1 (continued)

Sample Point	Sample Number	Date	Concentrations in ppb (µg/1) Chloroform ($CHCl_3$)	Bromodichloromethane ($CHCl_2Br$)	Chlorodibromomethane ($CHClBr_2$)
**Intake Canal	1	10/3/78	<1.0	<0.2	<0.2
Condenser Inlet 5 mins into chlorination cycle	4	10/3/78	3.2	1.7	0.7
Condenser Outlet 8 mins into chlorination cycle	6	10/3/78	4.0	2.1	0.8
Condenser Outlet 16 mins into chlorination cycle	8	10/3/78	3.9	2.0	0.6
Condenser Outlet 5 mins after chlorination cycle	10	10/3/78	<1.0	<0.2	<0.2
*Intake Canal	11	10/3/78	<1.0	<0.2	<0.2
**Intake Canal	1	11/1/78	<1.0	<0.2	<0.2
Condenser Inlet 5 mins into chlorination cycle	4	11/1/78	<1.0	<0.2	<0.2
Condenser Outlet 8 mins after chlorination cycle	6	11/1/78	7.1	3.8	1.1
Condenser Outlet 16 mins after chlorination cycle	7	11/1/78	7.1	3.3	0.9
Condenser Outlet 5 mins after chlorination cycle	10	11/1/78	7.3	3.6	0.9
*Intake Canal	12	11/1/78	<1.0	<0.2	<0.2

** Sample taken before chlorination cycle.
* Sample taken after chlorination cycle.

TABLE G-1 (continued)

Sample Point	Sample Number	Date	Concentrations in ppb (µg/l) Chloroform ($CHCl_3$)	Bromodichloromethane ($CHCl_2Br$)	Chlorodibromomethane ($CHClBr_2$)
**Intake Canal	1	11/15/78	1.1	<0.2	<0.2
Condenser Inlet 5 mins into chlorination cycle	3	11/15/78	9.3	4.2	1.3
Condenser Outlet 8 mins into chlorination cycle	8	11/15/78	8.7	4.6	1.5
Condenser Outlet 16 mins into chlorination cycle	9	11/15/78	8.4	4.4	1.4
Condenser Outlet 8 mins after chlorination cycle	12	11/15/78	1.6	<0.2	<0.2
*Intake Canal	14	11/15/78	1.2	<0.2	<0.2
**Intake Canal	1	11/29/78	<1.0	<0.2	<0.2
Condenser Inlet 8 mins into chlorination cycle	3	11/29/78	4.9	3.2	1.1
Condenser Outlet 8 mins into chlorination cycle	7	11/29/78	5.5	3.5	1.2
Condenser Outlet 16 mins after chlorination cycle	10	11/29/78	5.2	3.4	1.3
Condenser Outlet 5 mins after chlorination cycle	11	11/29/78	<1.0	<0.2	<0.2
*Intake Canal	14	11/29/78	<1.0	<0.2	<0.2

** Sample taken before chlorination cycle.
* Sample taken after chlorination cycle.

TABLE G-1 (continued)

Sample Point	Sample Number	Date	Concentrations in ppb (μg/l) Chloroform ($CHCl_3$)	Bromodichloromethane ($CHCl_2Br$)	Chlorodibromomethane ($CHClBr_2$)
**Intake Canal	1	1/09/79	<1.0	<0.2	<0.2
Condenser Inlet 5 mins into chlorination cycle	4	1/09/79	3.3	1.7	<0.2
Condenser Outlet 8 mins into chlorination cycle	5	1/09/79	7.3	1.1	1.7
Condenser Outlet 16 mins into chlorination cycle	8	1/09/79	6.5	1.0	1.7
Condenser Outlet 5 mins after chlorination cycle	10	1/09/79	<1.0	<0.2	<0.2
*Intake Canal	12	1/09/79	<1.0	<0.2	<0.2
**Intake Canal	1	1/23/79	<1.0	<0.2	<0.2
Condenser Inlet 5 mins into chlorination cycle	4	1/23/79	8.7	<0.2	0.2
Condenser Outlet 8 mins into chlorination cycle	6	1/23/79	5.9	0.99	0.30
Condenser Outlet 16 mins after chlorination cycle	7	1/23/79	5.4	0.87	<0.2
Condenser Outlet 5 mins after chlorination cycle	10	1/23/79	<1.0	<0.2	<0.2

** Sample taken before chlorination cycle.
* Sample taken after chlorination cycle.

TABLE G-2

Chlorine Feed Rate - JSSP

Date	Feed Rate	Cl_2 conc (mg/l)
7/06/78	3000 lbs	1.76
7/25/78	2400 lbs	1.55
8/29/78	2300 lbs	1.39
9/19/78	2400 lbs	1.56
10/03/78	2400 lbs	1.78
11/01/78	2250 lbs	1.75
1/15/78	2500 lbs	1.94
11/29/78	2500 lbs	1.94
1/09/79	2500 lbs	1.95
1/23/79	2500 lbs	1.95

The following is the calculation used to determine the Cl_2 concentration (mg/l):

$$Cl_2 \text{ conc} = \frac{Cl_2 \text{ Feed Rate}}{\text{CCW Flow Rate}} \times 83.22$$

CCW is the condenser cooling water flow rate.

83.22 is a conversion factor from:

lbs/24 hrs per gal/min to mg/l

$$\frac{\frac{\text{lbs}}{\text{24 hrs}}}{\frac{\text{gal}}{\text{min}}} = \frac{\text{lbs. min}}{\text{gals. 24 hrs}} \times \frac{\text{24 hrs}}{\text{day}} \times \frac{\text{day}}{\text{1440 min.}} \times \frac{\text{454 gm}}{\text{lb}} \times \frac{\text{1 gal}}{\text{3.785 l}} \times \frac{\text{1000 mg}}{\text{gm}} = 83.22$$

APPENDIX H

THE NEW CHLORINATOR

Based on the analysis of Phase I data, it was concluded that the fluctuating operation of the chlorinator was one major variable in qualifying and quantifying the chlorine feed rates at John Sevier. Thus, a search was initiated for a chlorination system that could accurately monitor the flow of chlorine gas. After study and several non-TVA site visits to inspect operating systems similar to those defined as necessary for the study, it was recommended that a Capital Control Series 800 Chlorinator and Series 910 flow meter and transmitter would be the best system for gathering feed rate data in the chlorination study. A comparative analysis of chlorine gas monitoring systems indicated that the Capital Control chlorine gas flow meter-transmitter measured flow by means of a variable orifice, and that the mechanism for monitoring gas flow was less susceptible to corrosion and possibly more reliable and more accurate than other available equipment. A diagram of the system is presented in Figure H-1. This system (i.e., chlorine and gas metering device) was installed at the plant in April 1977 for use during Phase II studies.

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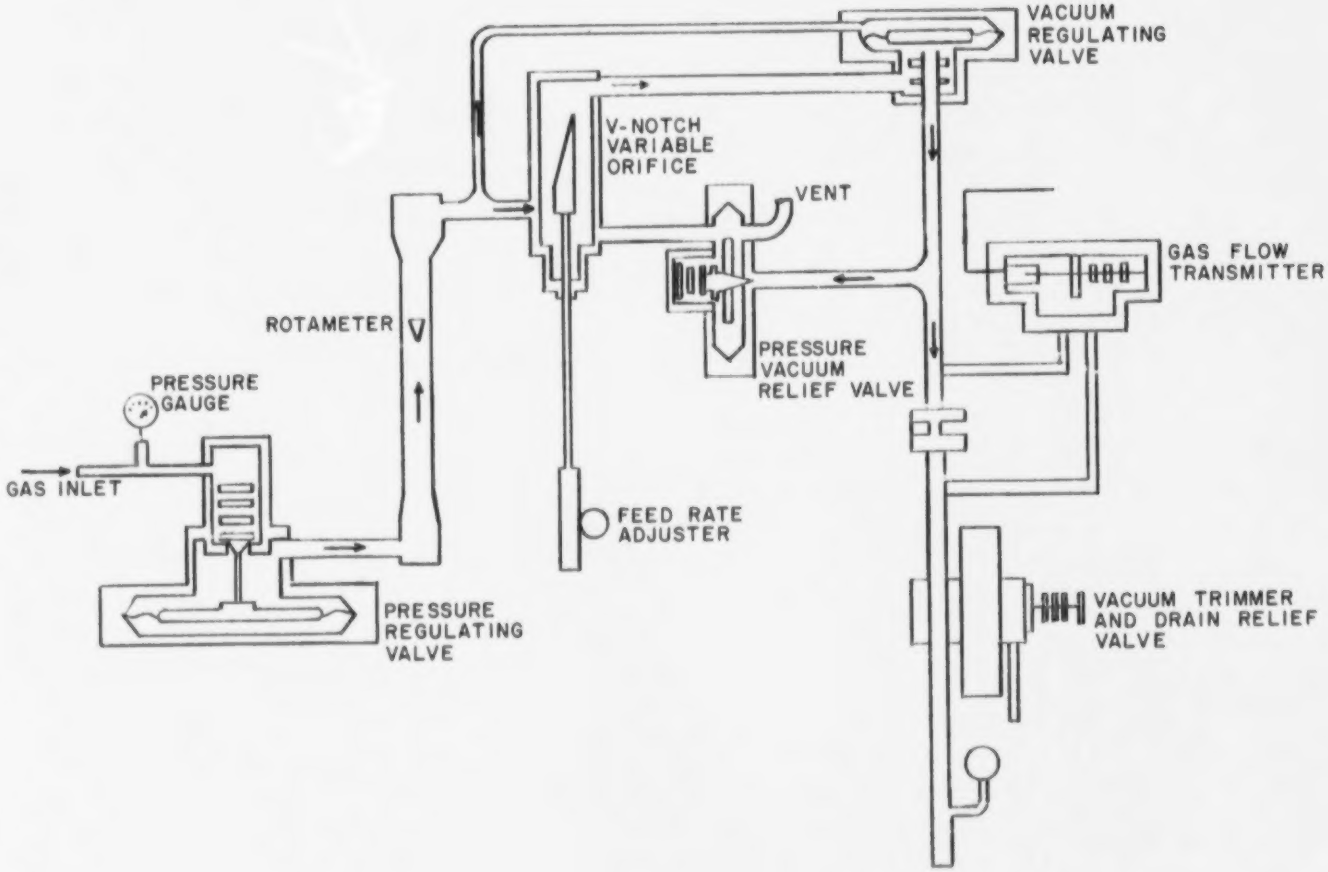
VACUUM
REGULATING
VALVE
V-NOTCH
VARIABLE
ORIFICE
VENT
GAS FLOW
TRANSMITTER
ROTAMETER
PRESSURE
VACUUM
RELIEF VALVE
PRESSURE
GAUGE
GAS INLET
FEED RATE
ADJUSTER
PRESSURE
REGULATING
VALVE
VACUUM TRIMMER
AND DRAIN RELIEF
VALVE

Figure H-1. Schematic diagram of capital control chlorinator.

APPENDIX I

CONDENSER INSPECTIONS

The following five memoranda were written as a result of the inspections of the condensers at the John Sevier Stem Plant. The result of these inspections further indicates that as long as a small amount of free residual chlorine is maintained at the condenser outlet, then condenser performance will not be impaired.

I. R. D. Moss had the opportunity to inspect the west side of Unit 4 condenser on August 25, 1977. The following summarizes the findings:

Inlet--No heavy growth of slime was noted. Three percent of the tubes were clogged by shells. A slight amount of slime was found in these tubes. A slight deposition was found in the bottom of all the tubes, which is a result of settling by suspended solids when taking the unit off line. This could easily be removed with a fingernail. Deposition was found about 2 feet from the ends of the tubes, but the rest of the tubes looked in satisfactory condition. The water box looked relatively clean.

Outlet-The outlet water box looked in satisfactory condition. The same type deposition in the bottom of the tubes was found. It could easily be scraped off. No clams, algae, or slime growth was found.

Overall, the condenser looked in good condition. The west side is also considered the worst side. Mr. Moss was very pleased with the condition of the condenser.

II. R. D. Moss had the opportunity to participate in the inspection of the west side of Unit 4 condenser on December 9, 1977, during the scheduled unit outage. The following summarizes the findings:

Inlet-No growth of slime was noted on the tube sheet or in the tubes. Only three tubes were blocked with shells. A slight deposit was found in the bottom of the tubes, which is a normal result of settling by suspended solids when taking the unit off line. Slight deposition was found about two feet from the end of the tubes, but the rest of the heat transfer areas looked in satisfactory condition.

The water box had a slime buildup of about 1/8-inch to 1/4-inch thick. It was quite difficult to remove, which indicates that it had been there for some time.

Outlet-The outlet water box looked similar to the inlet water box. The slime growth was on the sides of the water box but not on the tube sheet or in the tubes. No shells were found. The same type deposition found in the inlet side was also found in the outlet.

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This condenser looked in good condition. It looked slightly better than when it was inspected in August 1977. Very few tubes were obstructed with clams shells, and less slime was found during this inspection. This is especially encouraging since the west side is the side most likely to exhibit fouling due to the water turbulence.

III. R. D. Moss and C. V. Seaman had the opportunity to assist with the inspection of the Unit 1 condenser at John Sevier Steam Plant on March 23, 1978. The main reason for this inspection was to try to determine the cause or causes for the rapid loss of condenser performance within a one-week span when for four previous weeks the condenser performance had been very good with a zero chlorine feed rate. The following summarizes our findings after inspecting the west side of the condenser:

Inlet side--Hard slime formations of 1/4-inch deep were found on the walls of the water box. Due to the nature of the slime, it is apparent that it has been on the walls for some time. No slime was found on the face of the tube sheet or in the tubes. Ten to twenty tubes were clogged with fish approximately 5-inches long and 1 inch in diameter and crab-like species of approximately 3-inches long by 1-1/2-inches wide. No pitting or corrosion was found.

Outlet side--Hard slime formations of 1/4-inch deep were found on the walls of the water box as was found in the inlet side of the condenser. A thin layer of slime was found on the face of the tube sheet and in the tubes. This slime could easily be removed by rubbing with the fingers, but it was probably sufficient for reducing the condenser performance. No active corrosion or pitting was discovered.

Summary--The inlet side of the condenser contained a lot of trash and fish. It would seem unusual that fish of this size could be found in the condenser. The slime found in the outlet side of the condenser has been deemed responsible for the decrease in condenser performance experienced on Unit 1.

IV. On June 6, 1978, C. V. Seaman had the opportunity to inspect the west side of the Unit 4 condenser at John Sevier Steam Plant. The chlorination schedule for Unit 4 was six times a day for 10 minutes each at the following feed rates:

1/01/78 to 4/27/78 - 1500 lbs/24 hrs.
4/28/78 to 5/03/78 - 2000 lbs/24 hrs.
5/04/78 to 5/08/78 - 3000 lbs/24 hrs.
5/09/78 to 6/08/78 - 3500 lbs/24 hrs.

The following summarizes his inspection:

Inlet--The tube sheet face had a very fine layer of slime on it. A heavy layer of slime and dirt was found on the walls of the water box. No slime was noted in the tubes.

Outlet--Small patches of slime were found on the tube sheet face. Also, slime and dirt were found on the walls of the water box. No slime was found in the tubes, although some sand and dirt was noted in these tubes.

Summary--A biocide, such as chlorine, is beneficial in reducing biological growth within the condenser. The control of biofouling in the condenser may ensure good condenser performance.

V. On July 2, 1978, R. D. Moss and C. V. Seaman had the opportunity to assist in the inspection of the west side of Unit 2 condenser. This was the first opportunity to look at this condenser since the chlorination project was started at this plant in 1976. This unit has operated for over a year without being manually cleaned. It was not cleaned at this time since it was only down due to a boiler tube leak. Since we have been following the relationship of apparent cleanliness factor (ACF) and chlorine dosage, this condenser was of interest since it had dropped to a 69 percent ACF during May. Last summer at this time the ACF was 71 percent.

The following summarizes our findings:

Inlet--No slime was found on the facing of the tube sheet or in the tubes. Only a small number of shells were found in the water box. The usual slime and mud deposits were found on the supports and walls of the water box. No active pitting or corrosion was found.

Outlet--Thin patches of slime were found on the facing of the tube sheet. A thin film of slime was found in some of the tubes. Slime and mud were found on the walls of the water box. Slime was found on some of the supports inside the water box where we have not found slime before in other condensers. No active pitting or corrosion was found in the outlet side of this condenser.

Summary--This unit has operated longer than the other units, and, therefore, the slime formations are not unexpected considering the inlet water temperature (80°F) over the last few weeks. This unit is scheduled for a maintenance outage in the fall. Its normal outage was postponed due to the problems associated with the coal strike. This condenser should operate without a significant loss in efficiency for the remainder of the summer.

APPENDIX J

FACTORS INVOLVED IN CALCULATING THE APPARENT CLEANLINESS FACTOR

APPENDIX J

FACTORS INVOLVED IN CALCULATING THE APPARENT CLEANLINESS FACTOR

The ACF is a percentage of how well the condenser tubes in service transfer heat compared to how well a new tube would transfer heat. The basic formula is

$$\text{ACF (\%)} = \frac{U_o}{U_n} \tag{1}$$

where: U_o = the apparent heat transfer coefficient of a used tube in Btu/hr·ft²·°F

U_n = the apparent heat transfer coefficient of a new tube in Btu/hr·ft²·°F

To calculate U_o and U_n, the HEI and ASME codes require the use of approximately 30 variables. Some of these variables are based on the heat balance tests across the system which were conducted at John Sevier in the 1950's. Any changes in the actual efficiencies of the boiler and turbine which have occurred since the original tests will affect the calculation of ACF.

One variable is condenser duty, which is based on the relationship of unit load to heat rejection. This variable can never by computed accurately, but the overall formula is:

$$q = W_s\ (h_s - h_c) \tag{2}$$

For reheating-regenerative turbine-generator:

$$q - w_t\ (h_t - h_f) + w_r\ (h_r'' - h_r') + w_s h_c + 0.003\ p_f w_t - \frac{3413\ P_k}{\text{Generator Eff. x Mech. Eff.}} \tag{3}$$

where: q = condenser duty (Btu/hr)

w_s = steam flow to condenser (lb/hr)

h_s = enthalpy of steam to condenser (Btu/lb)

h_c = enthalpy of condensate (Btu/lb)

w_t = throttle steam flow rate (lb/hr)

h_t = enthalpy at throttle (Btu/lb)

h_f = enthalpy of feed water leaving final heater (Btu/lb)

w_r = steam flow rate to reheater (lb/hr)

h_r'' = enthalpy of reheat steam (Btu/lb)

h_r' = enthalpy of steam before reheating (Btu/lb)

$0.003\ p_f w_t$ - the work transfer in feed pump (psia · lb/hr)

P_k = power output (kW)

The enthalpy of the steam entering any condenser (h_s) cannot be determined from direct measurements unless the steam is superheated. Generally, the steam is in the wet vapor region, and the average dryness fraction has so far defied all attempts at measurement. Therefore, the only measurements for q were made in the initial energy balance calculations in the 1950's. Another way of describing the condenser duty is as follows:

$$q = \begin{matrix}\text{Heat added}\\ \text{by Boiler}\end{matrix} + \begin{matrix}\text{Heat added}\\ \text{by Pumps}\end{matrix} - [(\text{Generator output} + \text{mechanical output})\ (3413)] \qquad (4)$$

Another variable is the condenser cooling water flow rate (CCW). The basic formula for the flow rate is

$$CCW = \frac{q}{C_p \Delta T} \qquad (5)$$

where: q = condenser duty
C_p = specific heat of water
$\Delta T = T_{outlet} - T_{inlet}$

In terms of gallons per minute flow, the equation becomes

$$CCW = \frac{q}{8.021\ d\ C_p \Delta T} \qquad (6)$$

where: d = density of water (lb/ft^3) at a particular temperature

It is obvious that the CCW flow is only as accurate as q, and any changes in gross generation and the corresponding enthalpy changes (heat rate) will affect q. A simple calculation shows that for every 1 percent rise in heat rate of the boiler and turbine, there is a 1.74 percent change in q.

Boiler output for one kW production =	8000 Btu/hr
less number of Btu/hr per kW produced	-3413 Btu/hr
	4587 Btu/hr

1% rise = 80 Btu/hr

Therefore, $\frac{80}{4587} = 1.74\%$

It follows that if there is a 1 percent rise or loss in heat rate due to changes in the gross generation and/or enthalpies across the system, there will be a 1.74 percent change in the condenser duty and there will also be a 1.74 percent change in the calculation of the cooling water flow rate. While the flow rate may not actually change every time the gross generation changes, the ΔT, across the condenser will be changed. With a change in ΔT, there will also be a change in the chlorine consumption (temperature affects the FRC at the inlet; the FRC at the inlet affects the chlorine consumption in the condenser).

To further complicate the calculated CCW flow rate, the plant calculates CCW by determining the condensate flow theoretically corresponding to a particular gross generation and turbine back pressure from a graph. This value is then multiplied by 982 (theoretical h_c) and divided by 500 (theoretical heat capacity of water at a particular temperature) times the ΔT. Therefore, another source of error has been introduced.

Turbine back pressure is one of the few variables that can be accurately measured and can be measured to within 0.01 in. Hg. However, any changes in the air leakage will directly affect the back pressure. The air leakage into the steam side of the condenser can come from many sources, some of which are welds around tubes, pipes, and valves. The measurement of air leakage is crude and very inaccurate.

Since the back pressure is a function of air leakage and the losses in efficiency are demonstrated by the back pressure, the back pressure will be used to determine the logarithmic mean temperature difference (LMTD). The equation for the LMTD is

$$\mathrm{LMTD} = \frac{\theta_1 - \theta_2}{\log_e \dfrac{\theta_1}{\theta_2}} \qquad (7)$$

where: θ = difference between steam temperature and CCW inlet temperature
θ = difference between steam temperature and CCW outlet temperature

Another form of equation (6) would be

$$\mathrm{LMTD} = \frac{\Delta T}{\log_e \dfrac{t_s - t_1}{t_s - t_1}} = \frac{\Delta T}{\log_e \dfrac{\text{Temp. corresponding to back pressure } - T_{\text{inlet}}}{\text{Temp. corresponding to back pressure } - T_{\text{outlet}}}} \qquad (8)$$

Another variable is the design correction factor (DCF). This value is used to equate the ACF equation to any inlet water temperature other than 70°F. The value is found on a graph of inlet water temperature versus the design correction factors. The ability to differentiate the appropriate number from a graph may be impaired due to the quality of the graph.

The last variable is the tube velocity (TV). This value is very important when calculating ACF. Since biofouling may affect the TV, it is reasonable to assume that the TV should be known. However, TV is based on CCW. Here again, q becomes quite important. The formula for TV is:

$$\mathrm{TV} = \frac{\mathrm{CCW}}{\text{No. of tubes} \times \text{cross sectional area of tubes}} \qquad (9)$$

Now that the major factors involved in calculating the ACF have been described, the formula appears as follows:

$$\mathrm{ACF} = \frac{U_o}{U_n} = \frac{\dfrac{\dfrac{q}{\text{condenser surface area}}}{\text{LMTD}}}{\dfrac{\dfrac{q}{C_p \Delta T}}{\text{Total Cross Sectional Area of Tables}} \times \text{DCF}} \qquad (10)$$

or

$$\mathrm{ACF} = \frac{\dfrac{\dfrac{w_t(h_t - h_f) = w_r(h''_r - h'_r) = w_s h_c + 0.003\, p_f w_t - \dfrac{3413\, P_k}{\text{gen. effy. x mech. effy.}}}{\text{condenser surface area}}}{\dfrac{\theta_1 - \theta_2}{\log_e \dfrac{\theta_1}{\theta^2}} \text{ or } \dfrac{\Delta T}{\log_e \dfrac{t_s - t_1}{t_s - t_2}}}}{\dfrac{\dfrac{w_t(h_t - h_f) + w_r(h''_r - h'_r) + w_s h_c + 0.003\, p_f w_t - \dfrac{3413\, P_k}{\text{gen. effy. x mech. effy.}}}{8.021\, d\, C_p\, \Delta T}}{\text{Total Cross Sectional Area of Tubes}} \times \text{DCF}} \qquad (11)$$

APPENDIX K

A GENERAL OUTLINE FOR CONDUCTING A CHLORINE MINIMIZATION/OPTIMIZATION STUDY

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APPENDIX K

A GENERAL OUTLINE FOR CONDUCTING A CHLORINE MINIMIZATION/OPTIMIZATION STUDY

As a result of this extensive research effort, it would be appropriate to provide a general outline for conducting a chlorine minimization/optimization study. The outline should be considered general since the use of chlorine in a cooling system is very site-specific. The reader should be thoroughly familiar with the contents of Section 4 before reading this appendix.

I. Obtain Past Plant Operations Data

The basic concept of a minimization study is to systematically reduce the chlorine feed to the system as long as no loss in condenser efficiency is experienced. To determine this effect on condenser efficiency, the following plant operations data should be collected for the previous ten years on each unit for comparison purposes.

A. Gross generation (kW)
B. Condenser duty (10^6 Btu/hr)
C. Circulating water inlet temperature (°F)
D. Circulating water outlet temperature (°F)
E. Turbine back pressure (In. Hg)
F. Exhaust steam temperature (°F)
G. Air leakage (cfm)
H. Condenser cooling water flow rate (GPM)
I. Tube velocity (ft/sec)
J. Apparent cleanliness factor (%)
K. Dates of condenser cleaning
L. Past chlorination procedures (feed rates, lengths and frequency of feed, residuals measured)

All dates should be graphed and analyzed in terms of trends.

II. Obtain Past Water Quality Data

While all the necessary cooling system water quality data for conducting such a study may not be available, most plants measure some of them on a daily basis. The following data for the previous five years should be collected if available.

A. pH
B. Ammonia
C. Total suspended solids
D. Organic nitrogen
E. Conductivity
F. Chlorine demand

These data should be graphed and analyzed for trends.

III. Equipment

Two of the largest variables in a minimization study (see Section 4.) are the equipment which is used to feed the chlorine and the equipment which is used to measure the chlorine. Therefore, make sure that the chlorinator is reliable. It is recommended that a recorder be connected to the chlorinator, similar to the system described in Appendix H, so that an accurate measurement of the feed rate can be maintained.

It was determined from the field data that there exist significant problems associated with the accurate measurement of free and total residual chlorine concentration. This problem is illustrated by the instances of negative chlorine consumption, both across the condenser and across the cooling system (chlorine injection point to condenser outlet.) Until more research has been done in this field to develop a better method of analysis, this problem will continue if the chlorine to reduced nitrogen ratios are low.

At this time, the amperometric titration method is still the best method for conducting several grab sample analyses in a short period of time in the field. However, since this method requires considerable experience, it is recommended that all operators should be intimately familiar with the technique for measuring free and total residual chlorine.

IV. Sampling Locations

It is imperative that a location be found which will provide an easily accessible and representative sample of the condenser cooling water. The best sample points for monitoring chlorine in the condenser would be located in the inlet and outlet condenser water boxes. There should also be arrangements made so that a sample may be collected at a point immediately downstream of the chlorine injection point. At John Sevier, the chlorine was injected at the bottom of the circulating water intake pump suction well. Therefore, a sample point was made prior to the cone valve approximately 8 feet from the pump suction well. By making measurements from time to time at this point, some of the variabilities in the cooling water flow rate and the chlorinator feed rates can be measured.

Sampling points should also be established at the end of the discharge pipe to determine the amount of chlorine being released to the environment.

V. Field Studies

The field studies for a chlorine minimization/optimization project should cover a minimum of three years. The water quality criteria changes and the changes in plant operations, which may occur on a yearly basis, require that the field study encompass more than just one year of data gathering. It is recommended that two years be spent to determine the best chlorination regime for a plant, and one year should be spent monitoring the effects of the derived regime. The following scenario for conducting a minimization/optimization study will include this time frame.

A. Water Quality Data

Samples of the condenser cooling water should be collected each week during the study at the plant intake. These samples should be analyzed for the following parameters:

Temperature
pH
Ammonia as N
Organic nitrogen as N
Total organic carbon
Nitrates plus nitrites as N
Chlorine demand - 1, 5, and 10 minute*
Conductivity
Total suspended solids
Iron
Copper
Hardness as $CaCO_3$

The results of these analyses should be studied and the models presented in this report should be applied to determine: (1) if system characteristics in the models apply; (2) if unusual water quality conditions have occurred; and (3) the effect and potential effect of a certain water quality condition on the chlorination regime.

The effects of temperature, pH, ammonia, organic nitrogen, and chlorine demand on the chlorine regime have been discussed quite frequently in this report and in other literature on chlorination. Therefore, an accurate determination of these parameters is vital for determining the applicable chlorine feed rate for fouling control.

Such parameters as nitrates plus nitrites, iron, and copper are important with respect to the measurement of free and total residual chlorine. Nitrates and nitrites can interfere with the measurements, and copper and iron, in sufficient quantities, can poison the electrodes of the amperometric method of analysis which will yield high readings.

B. Plant Operations

Since the objective of a minimization study is to reduce the chlorine application as long as no loss in condenser efficiency has occurred, it is imperative that the following plant operations data be collected on each day of field testing.

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*The time of the chlorine demand tests should approximate the lengths of time it takes a particle of cooling water to arrive at critical points in the system. These points are: the condenser inlet, the condenser outlet, end of discharge pipe, etc.

1. Unit gross generation (kW)
2. Turbine back pressure (In. Hg)
3. Inlet and outlet circulating water temperature (°F)
4. Exhause steam temperature (°F)
5. Condensate temperature (°F)
6. Condenser cooling water flow rate (GPM)
7. Air leakage (CFM)

The above data should be grouped and analyzed for trends. The data should also be used for calculating the condenser performance by the method described in Section 9.

The steam-side calculation of condenser performance should be calculated by the plant a minimum of every two weeks at the unit's rated output. This data should also be analyzed for trends to determine the apparent results of reduced chlorine feeds and/or changes in frequency and duration of the chlorine feed. This data should then be compared to previous plant operations to determine the effect of chlorine minimization and optimization.

C. Measurements of Chlorine Residuals

Measurements for free and total residual chlorine concentrations should be made at least once per week for the entire daily test period at the inlet and outlet of the condensers. Measurements should be made on an intermittent basis (once per month) at the chlorine injection point and at the NPDES point of compliance.

During each chlorination period, at lease eight measurements should be made at steady-state conditions for both free and total residual chlorine. Eight measurements per chlorination period are required, based on a statistical determination. The most important period of measurement is that of steady-state which is the period of time in which the chlorinator has reached the desired feed rate after startup and before shutdown of feed.

Only the most experienced operators should make the measurements. The amperometric titrator, while a relatively accurate and quick method of analysis, requires considerable operator experience. The operator must be adept at determining an actual change of potential from the movements of the null point indicator and be able to differentiate these movements from those caused by electronic drift.

Since the measurements of free and total residual chlorine relies so heavily on operator competence, the operators should be assigned a specific sample point for the entire study.

At this writing, no answers have been provided as to why FRC measurements at the condenser outlet are higher than FRC measurements at the condenser inlet at certain times. This phenomenon has been noted at other power plants on different cooling water sources. Data to date have not shown any correlation between the occurrence of this phenomena and any particular water quality parameters measured. It is hypothesized that this phenomena may be caused by the reactions of chlorine and certain organic compounds in the water. These chloroorganic compounds are measured as FRC via the equilibrium changes in the sample from titrating with powerful reducing agents such as phenylarsine oxide. This hypothesis and other hypotheses will be tested in the near future. Therefore, extreme care should be used when making measurements and when analyzing results.

Care must also be used when measuring FRC and TRC concentrations at 0.1 mg/l and below. It should be noted that the instrument cannot detect electrode potential changes below 0.02 mg/l. Furthermore, the electrode response below 0.1 mg/l can be quite deceiving since the beginning of the titration is so close to the end point. Additional explanation of the problems associated with measuring FRC and TRC may be found in Section 4.

D. Variance of Feed Rate, Duration, and Frequency of Feed

If the power plant has more than one unit, different frequencies and durations of feed may be tested on different units simultaneously, as long as the units are of the same size. One unit should be used as a control unit and should remain at the same frequency and duration as was the past plant practice.

More frequent daily chlorine applications for shorter durations and less frequent chlorine applications for longer durations should be tested. The test period to determine the optimum frequency/duration regime should be at least two years. The final year of testing should have all units but the control condenser operating on the same frequency/duration regime.

All decisions with regard to the optimum frequency/duration regime should be based on the effect these regimes have on the condenser performance. A statistical approach should be used to determine the best regime.

The chlorine feed rate should be reduced as long as no loss in condenser efficiency is noted. These reductions should follow an orderly procedure based on the water quality data and plant operations data. A free residual chlorine concentration of no less than 0.1 mg/l should be maintained at the condenser outlet. Reductions of the chlorine feed should not take place any faster than every three months, but this length of time will depend on the water quality at each facility. This period of time will allow the accumulation of sufficient data to determine the effect of the feed rate on the condenser performance.

If the feed rate is to be reduced such that FRC concentrations below 0.1 mg/l at the condenser outlet are to be tested, this reduction should only be made if no ambiguities have been noted in the ability to measure the chlorine concentrations. While 0.1 mg/l is quite low, it would not be advisable to reduce the feed rate below 0.1 mg/l if the following conditions occur:

1. The Cl_2:N ratios in conjunction with kinetic rate theory indicate that no FRC should be measured, yet concentrations of FRC are being detected.

2. Excessive electronic drift in the titrator as end-point is reached.

3. Higher FRC concentrations measured at the condenser outlet than at the inlet.

For further explanation regarding the impact of these phenomena on the minimization/optimization of chlorine, please see Section 4.

Tests at a zero chlorine feed rate should also be conducted at times of high and low inlet water temperatures. The tests should not terminate until a significant loss in condenser performance has occurred (5 percentage points). These tests will determine (1) the necessity for chlorination; (2) the time of year most susceptible to fouling; and (3) lag time between the cessation of chlorination and the evidence of unit fouling.

After two years of tests, the recommended feed rates, frequency and duration of feed should be maintained for at least a year, and the condenser performance should be monitored every two weeks to determine the success or failure of the chlorination regime.

E. Condenser Inspections

During the minimization/optimization study, it is very important that the unit efficiency be monitored to determine the success or failure of the chlorination regime. However, many inherent problems are associated with the accurate determination of unit efficiency. (See Section 4.) In most cases, by the time the turbine back pressure indicates that fouling has occurred, it is too late to do anything about it.

Therefore, at every opportunity, the condensers should be visually inspected. The inlet and outlet water boxes should be inspected for slime growth and silt deposition. The water boxes should be cleaned so that the deposition does not become so great that it will flake off and plug the condenser tubes. We recommend cleaning the water box walls every two years or less.

The tube sheet should be inspected for slime growth. Slime on the tube sheet is a strong indicator of even more slime in the tubes. Normally, if there is slime growth, the slime can be found more prevalent at the condenser outlet than at the condenser inlet.

Obviously, the tubes should be inspected for growth. If tubes are plugged via sticks, clam shells, or other debris, there is a good chance that biofouling will occur in the tubes since no chlorine can reach the growth in the tubes. Those tubes not plugged by debris should be inspected closely. If there is a slick feeling to the tubes, samples should be collected via ASTM standards, preserved, and analyzed.

The tubes and tube sheet should also be inspected for scale deposition, corrosion, or erosion. The evidence of scaling or pitting will require other methods of treatment, most likely side-stream treatment, in addition to chlorination for biofouling control.

VI. Followup

After the chlorine minimization/optimization study has been completed, the water quality characteristics, the frequency of feed, the duration of feed, the chlorine feed rate, and the plant operations data should be monitored intermittently for several years. Since the condenser cooling water characteristics will change from year to year, it is important to determine the effect the chlorine regime has on the unit efficiency over the long term (usually 5 years). While the monitoring of chlorine residuals should occur each week on each condenser, the other parameters mentioned should be evaluated monthly. Significant changes in inlet water temperature, for example, will necessitate changes in the chlorine feed rate.